AN ABSTRACT OF THE THESIS OF

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Title: Calibrating the Highway Safety Manual Predictive Methods for Oregon Rural State Highways

Abstract approved:

Karen K. Dixon

The first edition of the Highway Safety Manual (HSM) provides a quantitative approach to predict the safety of transportation facilities based on the recently developed scientific methods. This approach, known as the predictive method, was developed for several states in the United States. Due to differences in driver population, weather condition and other issues, the State of Oregon is expected to calibrate these predictive models before using them. By locality, the existing predictive methods can be divided into two parts: rural highway predictive method and urban highway predictive method. This thesis focuses on the calibration project for the rural predictive models. Therefore, in the first part of this thesis, the author will illustrate the calibration process and calibration results for the rural facility types, including rural two-lane, two-way roads and rural multilane highways. Also, after the calibration project, the author found a new calibration sample size estimation procedure which is more statistically reliable than the current HSM sample size determination process. This new statistical estimation method will be explained and recommended for future calibration projects.

Calibrating the Highway Safety Manual Predictive Methods for Oregon Rural State Highways

by

Fei Xie

A THESIS

submitted to

Oregon State University

in partial fulfillment of

the requirement for the

degree of

Master of Science

Presented March 3, 2011

Commencement June 2011

Master of Science thesis of Fei Xie presented on March 3, 2011

APPROVED:

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Fei Xie, Author

ACKNOWLEDGEMENTS

Firstly, I would like to thank Dr. Karen Dixon who has been my major advisor in Transportation Engineering for more than two years. She showed her continuous support for my M.S. study and research. Her guidance and encouragement helped me in all the time of my study in Oregon State University. In my mind, she is one of my best mentors in my life.

I also appreciate all of my committee members who spending their valuable time for my thesis defense.

In addition, I would like to thank the members of the Oregon Department of Transportation (ODOT) Project Technical Advisory Committee for their advice and assistance in the calibration project. I would also like to thank the Oregon Transportation Research and Education Consortium (OTREC) for funding the project and the ODOT for managing the project.

At last but not the least, I want thank my fiancée, Nawei Liu, who has always trusted me and supported me during my graduate study at Oregon State University.

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1.0 INTRODUCTION

The recently released *Highway Safety Manual* (HSM), published by the American Association of State Highway and Transportation Officials (AASHTO), provides a quantitative approach to predict the safety of transportation facilities based on the recently developed scientific methods. This approach, known as the predictive method, exists for three facility types: rural two-lane, two-way roads, rural multilane highways, and urban and suburban arterial highways. The initial step of this predictive method approach is to use safety performance functions (SPFs), which are statistically derived equations, to predict the average crash frequency for a specific facility type under base conditions. When characteristics of facilities differ from the base condition, then crash modification factors (CMFs) are applied to account for these differences.

Since the predictive method was developed from the crash data for a subset of states in United States, the direct application of this approach to local conditions may result in low precision estimations. This reduced precision may be due to differences in crash reporting thresholds, weather condition, driver populations, animal populations, or terrain. Highways in specific local conditions may experience significantly different prediction values. To overcome these differences, the HSM recommends that local agencies should either develop SPFs for their local conditions or develop calibration factors to adjust the HSM SPFs to account for the expected changes in crash frequency. Currently, the State of Oregon has elected to develop the calibration factors for the HSM predictive methods. The success of this calibration effort enables the State of Oregon to convincingly use the predictive method in the HSM. Also, since the State of Oregon is one of the leading agencies to test this calibration procedure, the whole process detailed in this project is expected to benefit future predictive methods and provide guidance for other agencies in their calibration projects.

The calibration project included two research groups, Oregon State University (OSU) and Portland State University (PSU). This thesis reviews the HSM calibration procedures conducted by the OSU group, including the calibration projects for rural two-lane, two-way roads and rural multilane highways. In addition, the author identified two critical data collection issues including the minor road annual average daily traffic (AADT) and minimum sample size for under-represented crash locations. Finally, since the required sample size in the HSM may be impractical for local conditions, the author did further research on the development of a new sample size determination procedure. This thesis also illustrates this new method.

2.0 LITERATURE REVIEW

This section reviews crash reporting thresholds in Oregon and neighboring states, the predictive methods in the HSM, and an AADT estimation procedure.

2.1 Crash Reporting Thresholds

This section reviews crash reporting thresholds in Oregon and two neighboring states, California and Washington.

2.1.1 Crash Reporting Threshold in Oregon

The crash reporting threshold in Oregon is for crashes that involve more than $1,500 of damage (*Wills, 2006*).The State of Oregon is a self-reporting state and citizens have the legal responsibility to report crashes. The crash analysis and reporting unit cannot, therefore, guarantee that all qualifying crashes are included in the crash data system.

2.1.2 Crash Reporting Thresholds in California and Washington

The crash reporting threshold in California is for crashes that exceed $750 in damage (*California Department of Motor Vehicles, n.d.*), while the threshold in Washington is for crashes with more than $700 damage (*Washington State Legislature, n.d.*). Both of these neighboring states have much lower thresholds than the State of Oregon. The HSM procedures include “default” crash distribution values that are based on California and Washington data, so these varying reporting thresholds can dramatically affect reported (and evaluated) crashes.

2.2 Predictive Methods in HSM

The newly released HSM includes a predictive method to estimate the expected average crash frequency of a roadway network (*AASHTO, 2010*). The predictive method is a scientific approach to estimate the crash frequency using the AADT and geometric characteristics during a given time period. The following sections review the HSM predictive methods, facility types, crash assignments, and calibration procedures.

2.2.1 Predictive Models

For each specific facility type, the HSM includes a predictive model (*AASHTO, 2010*). The predictive model is shown in Equation 2-1. To estimate the predicted average crash frequency, $N_{predicted}$, the initial step is to apply a regression model, known as the SPF, to estimate the crash frequency of sites under base conditions. When the actual conditions of roadway varies from the base condition, CMFs are applied to account for the changes. When the actual conditions are the same as the base condition, specific CMFs equal 1.00. To adjust the predictive models to local conditions, the next step is to apply the calibration factor, C.

$$N_{predicted} = N_{spfx} \times \left(CMF_{1x} \times CMF_{2x} \times \cdots CMF_{yx}\right) \times C_x \quad (2\text{-}1)$$

Where:

$N_{predicted}$ = predicted average crash frequency for a specific year for site type x;

N_{spfx} = predicted average crash frequency determined for base conditions of SPF developed for site type x;

CMF_{1x} = crash modification factors specific to SPF for site type x; and

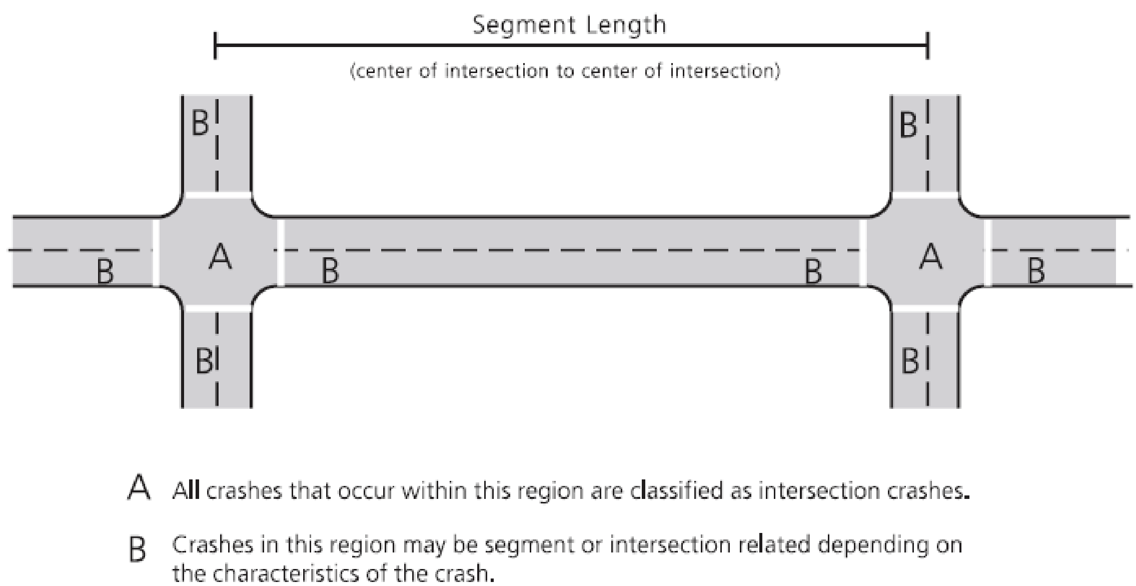
C_x = calibration factor to adjust SPF for local conditions for site type x.

2.2.2 Facility Types

Three types of roadways are included in Part C of the HSM (*AASHTO*, *2010*): rural two-lane, two-way roads, rural multilane highways, and urban and suburban arterials. For each roadway type, there are generally two site types, roadway segments and intersections.

2.2.3 Crash Assignment

Observed crashes may be assigned to either roadway segments or intersections (*AASHTO*, *2010*). Definitions of roadway segments and intersections are depicted in Figure 2.1. As shown in Figure 2.1, observed crashes located in region A are assigned to intersections. Crashes that occur in region B could be either intersection related or roadway segment related. The assignment of crashes in region B could be determined by analyzing the crash characteristics. Generally, crashes that occur on an intersection approach beyond 250 ft are assigned to roadway segments.



Source: AASHTO, 2010

Figure 2.1: Definition of Roadway Segments and Intersections

2.2.4 Calibration of Predictive Models

To account for differences between jurisdictions by geographic area, the HSM recommends a calibration procedure which uses a multiplicative calibration factor to adjust the predictive models (*AASHTO, 2010*). For each facility type, agencies should develop a calibration factor. The calibration factor is a ratio of the total observed crash frequencies for a selected set of sites to the total expected average crash frequency without calibration factors for the same sites. When the total observed crash frequencies are larger than the predicted crash frequencies, the calibration factors should be larger than 1.00. When there are fewer crashes observed than are predicted, these values should be smaller than 1.00.

For the HSM calibration procedure, each facility type requires a minimum sample size of 30 to 50 sites (*AASHTO, 2010*). Where possible, these calibration sites should be randomly selected from a larger set of candidate sites. For each facility type, the entire group of sites should represent a total of at least 100 crashes per year. If fewer than 30 sites exist in a jurisdiction, then the data set should include all available sites. The calibration data includes two types of data: (1) Total observed crash frequency for a period of time (one or multiple years); (2) All site characteristic data required by the predictive models. After the data collection, the calibration factor can be computed using Equation 2-2. The calculation is performed separately for each facility type.

$$C = \frac{\sum_{all\ sites} observed\ crashes}{\sum_{all\ sites} predicted\ crashes} \qquad (2\text{-}2)$$

2.3 Estimation of Traffic Volume

Mohamad et al. (*1998*) developed an AADT prediction model for county roads in Indiana. The field data were collected from 40 counties in Indiana. The AADT model was generated based on multiple linear regression. The authors evaluated several variables. Before the variable selection, all independent variables were centered to reduce the correlation problem between independent variables. The authors found that the AADT of county highways is dependent on if the road is a rural or urban road, if the county road has easy access to the state highway, the total state highway mileage of a county, and the total arterial mileage of a county.

2.4 Summary of Literature Review

This section reviews the differences in the crash reporting threshold between the State of Oregon and other neighboring states, the predictive methods and the calibration process in the HSM, and the method to estimate traffic volume. This literature review directly contributed to the calibration effort for the HSM predictive methods in the State of Oregon.

3.0 RESEARCH OBJECTIVE AND SCOPE

The calibration process for the HSM predictive method can be divided into two parts: rural highways and urban/suburban highways. The author focuses on the rural calibration effort for the State of Oregon. For rural highway predictive methods, there are two chapters in the HSM: Chapter 10-Predictive Method for Rural Two-Lane, Two-Way Roads; and Chapter 11-Predictive Method for Rural Multilane Highways. Each facility type model within these two chapters must be calibrated. Table 3.1 depicts all models that require calibration for this project. Furthermore, due to the relatively high crash reporting threshold, many property-damage-only (PDO) crashes are not reported in Oregon. To overcome this bias, the author then developed calibration factors for fatal and injury crashes. Moreover, since the HSM recommends using locally derived values, a comparison is given to show differences in calibration results between using HSM default values and locally derived values.

Table 3.1: HSM Rural Models to Calibrate

Facility Type	Segment Types	Intersection Types
Rural Two-Lane, Two-Way Roads	• Undivided (R2)	• Three-Leg Stop (R3ST) • Four-Leg Stop (R4ST) • Four-Leg Signalized (R4SG)
Rural Multilane Highways	• Undivided (MRU) • Divided (MRD)	• Three-Leg Stop (MR3ST) • Four-Leg Stop (MR4ST) • Four-Leg Signalized (MR4SG)

Source: AASHTO, 2010

In addition to the calibration effort, the author analyzed the calibration process. Where possible, the author identified candidate ways to improve the calibration method. During the process, the author found a new sampling procedure providing an improved estimate of the required sample size. With this method, future researchers can minimize their sampling effort without lowering the precision of results.

4.0 CALIBRATION PROCESS OVERVIEW

Each facility type defined in the HSM requires a calibration factor. The process to generate this factor in this project can be summarized as five steps:

Step 1: The author estimated an appropriate initial sample size which was usually 50 sites. With this sample size, he conducted a random sampling procedure to select calibration sample sites among the pool of all candidate sites.

Step 2: After the site selection, the author collected observed crash data for the selected sites. If the total observed crash frequency ($N_{observed}$) of all sites did not meet HSM requirements or the author's expectation, he then increased the sample size until it met the requirements.

Step 3: When selected sites met the sample size requirement, the author collected road characteristic data of all selected sites. For roadway segments, he divided the sites into homogenous segments based on changes of roadway characteristics.

Step 4: Following collection of road characteristic data, the author computed an unadjusted crash frequency (calibration factors are not applied) for each segment or intersection. Equation 4-1 depicts the calculation process in this step. N_{spf} is the predicted crash frequency under base conditions. When characteristics are different from the base condition, CMFs are applied by multiplying the N_{spf}. The author reviews these base conditions in Section 6.2

$$N_{predicted\ (unadjusted)} = N_{spf} \times (CMF_1 \times CMF_2 \times \cdots CMF_n) \qquad (4\text{-}1)$$

Step 5: The author then computed the calibration factors using Equation 4-2.

$$C = \frac{\sum_{all\ sites} N_{observed}}{\sum_{all\ sites} N_{predicted\ (unadjusted)}} \qquad (4\text{-}2)$$

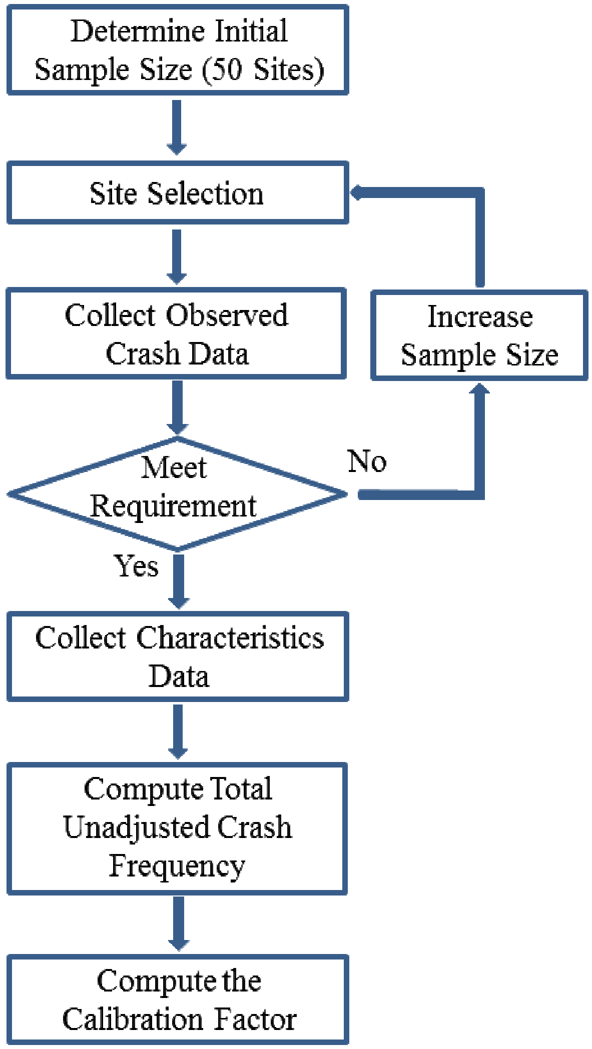


Figure 4.1: Flow Chart of the Calibration Process

Figure 4.1 depicts the flow chart of the calibration process in this project. The calibration process for all facility types is based on this chart. Details of the calibration process are depicted in the following sections.

5.0 SITE SELECTION

This section reviews the calibration sample size determination for all facility types and specific sampling procedures for roadway segments and intersections.

5.1 Sample Size Determination

The HSM minimum required sample size for each facility type is 30 to 50 sites. In addition, all selected sites for one facility type should represent 100 crashes per year. However, for rural intersections, although the sample size has been increased for many facility types, the total represented crashes still cannot reach 100 crashes. Due to the complex data collection effort, an alternative way to address this limitation is to reduce the required number of crashes. Therefore, the author determined the sample size based on the average Oregon crash history for each facility type in the data collection effort in this project. In Oregon, R4SG, MRD, MR4ST and MR4SG have a limited number of sites available. Therefore, all sites of these facility types are included in the calibration sample. Table 5.1 depicts the sample size by facility type.

Table 5.1: Sample Size by Facility Type

Facility Type		Sample Size*
Rural Two-Lane, Two-Way Roads		
Segments		
R2	2-lane Undivided	75
Intersections		
R3ST	3-leg, minor STOP	200
R4ST	4-leg, minor STOP	200
R4SG	4-leg, signalized	25
Rural Multilane Highways		
Segments		
MRU	4-lane undivided	50
MRD	4-lane dividied	19
Intersections		
MR3ST	3-leg, minor STOP	100
MR4ST	4-leg, minor STOP	107
MR4SG	4-leg, signalized	34

* Number of sites selected for the calibration effort

5.2 Sampling Procedures

Since the state highway system has relatively thorough and correct data, the authors started with the pool of all possible candidate facilities for rural state highways. To overcome site selection bias, the authors applied a random sampling procedure to randomly select samples from the population. By conducting a random sampling procedure, the authors firstly developed a sampling frame which includes all available candidate sites in Oregon, and then randomly selected sites from the sampling frame. Furthermore, the R4SG has a limited number of sites along state highways, and may be present along county or city roads. As a result, the author also included all R4SG intersections along county or city roads in the sample.

Site selection methods for roadway segments and intersections may be different, and these methods will be stated separately.

5.2.1 Roadway Segment Site Selection

In the HSM, there are three roadway segment types, R2, MRU and MRD. The site selection was based on random selection from the state highway systems. To build up an appropriate sampling frame for each facility type, the author firstly used the *Functional Classification and National Highway System Status on Oregon State Highways* (ORStateHwysFCandNHS) to select rural state highways. The next step is to use the Oregon Department of Transportation (ODOT) lane report to classify roadway segment types. Table 5.2 depicts an example of the lane report (HWY009 MP from 212.24 to 212.69). In Table 5.2, lane width 1 to 6 indicates the number of lanes and width of each lane. Median type indicates if a median is present and the type of the median. Generally, these two variables are key features used to classify the roadway segment types.

As a qualified R2 roadway segment, the lane report should indicate that two lanes are present and the median type should show “undivided.” All qualified R2 roadway segments were included in the population, and then the author divided all segments to approximately 2 miles segments which are the sampling units in the sampling frame. Finally, the author randomly selected 75 two-mile segments characterized by an average

131 crashes per year (thereby meeting the HSM calibration requirement of 100 crashes per year).

Table 5.2: ODOT Lane Report

<table>
<tr><th rowspan="2">Mile Point (MP)</th><th rowspan="2">Intersection Codes (explanation in Section 5.2.2)</th><th colspan="6">Lane Width (ft)</th><th rowspan="2">Shoulder Type</th><th colspan="2">Shoulder Width (ft)</th><th colspan="2">Median</th></tr>
<tr><th>6</th><th>5</th><th>4</th><th>3</th><th>2</th><th>1</th><th>Lt</th><th>Rt</th><th>Type</th><th>Width (ft)</th></tr>
<tr><td colspan="13">Highway #: 009 Oregon Coast Highway</td></tr>
<tr><td>212.69</td><td>|</td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>2</td><td>2</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.69</td><td>C = 3 = C</td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>2</td><td>2</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.68</td><td></td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>5</td><td>5</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.66</td><td></td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>5</td><td>5</td><td>Undivided</td><td>6</td></tr>
<tr><td>212.65</td><td></td><td>0</td><td>0</td><td>20</td><td>12</td><td>12</td><td>20</td><td>Paved</td><td>0</td><td>0</td><td>Undivided</td><td>14</td></tr>
<tr><td>212.61</td><td>C = | = C</td><td>0</td><td>0</td><td>20</td><td>12</td><td>12</td><td>20</td><td>Paved</td><td>0</td><td>0</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.53</td><td>C = | = C</td><td>0</td><td>0</td><td>20</td><td>12</td><td>12</td><td>20</td><td>Paved</td><td>0</td><td>0</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.45</td><td>C = 3 = C</td><td>0</td><td>0</td><td>20</td><td>12</td><td>12</td><td>20</td><td>Paved</td><td>0</td><td>0</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.37</td><td>C = |</td><td>0</td><td>0</td><td>20</td><td>12</td><td>12</td><td>20</td><td>Paved</td><td>0</td><td>0</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.37</td><td>| = C</td><td>0</td><td>0</td><td>20</td><td>12</td><td>12</td><td>20</td><td>Paved</td><td>0</td><td>0</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.32</td><td></td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>5</td><td>8</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.31</td><td>S</td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>8</td><td>8</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.27</td><td>= | W | =</td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>4</td><td>4</td><td>Undivided</td><td>0</td></tr>
<tr><td>212.24</td><td>|</td><td>0</td><td>0</td><td>12</td><td>12</td><td>12</td><td>12</td><td>Paved</td><td>4</td><td>4</td><td>Undivided</td><td>0</td></tr>
</table>

The site selection method of MRU is similar to the method used for R2. Instead of two lane segments, four lane segments were selected and the median type should indicate there was no median. However, different from R2 segments, a large number of MRU segments were relative short in length, and too short segments might have no crashes or inflate crash predictions based on the short segment length. Therefore, segments which are shorter than 0.5 miles are not included in the sampling frame. Also, long segments might contain many homogeneous segments, so the author divided segments longer than 2.5 miles into 2 miles segments. As a result, the length of the sampling unit ranged from 0.5 mile to 2.5 mile. Finally, the author randomly selected 50 roadway segments from the data pool and these segments were characterized by an average of 121 roadway crashes per year.

The author applied the same selection method to MRD. The median type should indicate there is a median. There are only a few MRD segments in Oregon. All these segments were included in the sample. There are 19 segments, and the total length is 8.27miles.

5.2.2 Intersection Site Selection

In the HSM, there are six intersection types, R3ST, R4ST, R4SG, MR3ST, MR4ST and MR4SG. Except for R4SG, the author based site selection on random selection from the state highway systems. Because state highways have few R4SG sites, intersections of this type along county and city roads are also included in the sample. Before the random selection, the author also used the ODOT lane report to classify all potential sites for each facility type. The intersection code in the lane report indicates the associated intersection type and jurisdictions of the cross roads. The intersections have five district codes. The first and fifth codes indicate the jurisdiction type of the cross roads. For example, "s" indicates that the cross road is a state highway, while "k" represents county roads and "c" represents city roads. When only one of code 2 and 4 shows "=" at one MP, then the main road has a three leg intersection at that location. When both of code 2 and 4 show "=" at one MP, there is a four leg intersection. When the code of 3 shows "3", the intersection is signalized controlled.

After the identification of the initial sampling frames of each facility type, the author conducted a random selection for each type until 30 to 50 sites were selected. When selected sites could not represent 100 crashes per year, the sample size was increased. During the site selection, the author used Google Earth to examine specific facility types.

Rural intersections have very few reported crashes in Oregon, and the target of 100 crashes per year for each facility type was not practical for this project. Therefore, the author considered practical sample sizes for different facility types based on the average Oregon crash history. The average crash frequency per site of MR3ST is consistently low and increasing the sample size has little effect on the increase of the precision, therefore a sample size of 100 sites was used for this intersection type. Since R3ST and R4ST are both common intersection types in rural systems, the author increased the sample size of each of them to 200. All candidate sites of R3SG, R4ST, and R4SG in Oregon are included in the calibration sample.

After the site selection, the authors could collect observed crash data and road characteristic data for these sites and calculate calibration factors for all facility types.

6.0 DATA COLLECTION

The calibration project needs two types of data. The first one is the observed crash data and the second one is road characteristic data. The study period is from the year of 2004 to the year of 2006. For this project, the author used all types of road characteristic data (i.e. HSM default values were not used).

6.1 Observed Crash Data

The author obtained the observed crash data from year 2004 to 2006 from the crash database provided by the Oregon Department of Transportation's Statewide Crash Data System (CDS). Crash data for 2007 or later were not available when this project was initiated. For roadway segments, the author used all crashes located within these segments limits. For intersections, the author acquired all crashes within intersections and on the intersection legs (within 250 feet (15.3m)). The author then acquired different types of crash information to indicate if crashes on the intersection legs were associated with the intersection or roadway segment. These data included crash identity number, crash type and collision type, character of roads, intersection related designated by officers, direction from intersection, and direction of travel. The method to designate if crashes are intersection related is illustrated in Section 7.2. For each crash record, the author also obtained the crash severity level which was used to compute calibration factors of safety performance functions for fatal and injury crashes.

6.2 Road Characteristic Data

This section reviews the required data elements needed for the predictive models. The author also illustrates the data collection procedures for these data.

6.2.1 Required Data Elements

Required data elements vary for predictive models of different facility types. Table 6.1 depicts all data elements needed for the calibration project. Since the first edition of the

HSM does not include CMFs for MR4SG, the authors only collected the AADT of the major road and the AADT of the minor road for the MR4SG.

Table 6.1: Required Data Elements

Data Elements	**Data Requirements per Facility Type**								
	Rural Two-Lane, Two-Way Roads				**Rural Multilane Highways**				
	R2	R3ST	R4ST	R4SG	MRU	MRD	MR3ST	MR4ST	MR4SG
AADT of Major Road	X	X	X	X	X	X	X	X	X
AADT of Minor Road		X	X	X			X	X	X
Segment Length	X				X	X			
Lane Width	X				X	X			
Shoulder Width	X				X	X			
Shoulder Type	X				X				
Horizontal Curve Data	X								
Vertical Grades	X								
Driveway Density	X								
Centerline Rumble Strips	X								
Passing Lanes	X								
Two-Way Left-Turn Lanes (TWLTLs)	X								
Roadside Hazard Rating	X								
Side Slope					X				
Median Type and Width						X			
Lighting	X	X	X	X	X	X	X	X	
Automated Speed Enforcement	X				X	X			
Intersection Skew Angle		X	X				X	X	
Intersection Left-Turn Lane		X	X	X			X	X	
Intersection Right-Turn Lane		X	X	X			X	X	

6.2.2 Data Collection Methods

The sources for AADT of major road and minor road depend on the various jurisdictions where the roads are located. If roads are state highways, their AADT can be acquired from the *ODOT Traffic Volumes and Vehicle Classification Report*. If roads are maintained by other agencies, such as counties or cities, the author contacted the associated public work or road departments to request AADT information. In many cases these other agencies do not have AADT data for the minor roads at intersections.

Therefore, the authors generated a set of AADT estimation models to estimate AADTs for these roads. When a state highway intersected a road without AADT information, the authors initially assumed the state highway to be the major roads. If the AADT estimation models indicate that the locally maintained road carries more traffic volume, the major and minor road intersection assumptions were then modified. Section 7.1 provides details of the AADT estimation model.

The author collected lane width, shoulder width, shoulder type, passing lane, and median width information from the *ODOT State Highway Lane Report* (see Table 5.2). The author also acquired horizontal curve data including curve length, curve radius, the presence of spiral transition curve, and the superelevation from *ODOT State Highway Horizontal Curve Report* (see Table 6.2).

Table 6.2: Horizontal Curve Report

Roadway		Beginning Mile Point	Contract ID	Location Seq #	Super Elev Rate		Spirals			
Degree Curve Ang (degrees)	Dir	Central Ang (degrees)	Curve Len (ft)	Tangent Len (ft)			Len (ft)	Ang (degrees)	Tan (ft)	Increase Rate
Highway #: 026 MT. HOOD Hwy										
1		80.48	26	180	0	Spiral In	0	0	0	0
0		0	0	0		Spiral Out	0	0	0	0
1		80.32	26	180	0	Spiral In	300	9	0	2
6	L	17.7958	296.6	148.84		Spiral Out	300	9	0	2
1		80.23	26	180	0	Spiral In	0	0	0	0
0		0	0	0		Spiral Out	0	0	0	0

Table 6.2 indicates that for Highway 26, a horizontal curve is located from MP 80.32 to MP 80.48. The length of the horizontal curve, which includes spiral transitions, is 0.16 miles or the distance between MP 80.32 and MP 80.48. The degree of curvature is 6 degrees. The curve radius can be directly calculated by using Equation 6-1 (Radius: 954.9 ft for this curve). In addition, there is no superelevation present along the curve, and there are two spiral curves with lengths of 300 ft.

$$Radius = \frac{5729.58}{Degree\ of\ Curvature}\ (ft) \tag{6-1}$$

Where the degree of curvature is the central angle subtended by a chord of 100 ft.

The author obtained vertical grade information from the *ODOT State Highway Vertical Grade Report*. Table 6.3 depicts an example of this data and shows the vertical grade information of Highway 26 from MP 80.4 to MP 90.21. For example, the grade from MP 80.4 to MP 82.91 is 1.03%.

Table 6.3: Vertical Grade Report

Beginning Milepoint	Location Seq #	Percent Grade	SAG/ CREST	Curve Length (ft)	Contract ID	Estimated Data
Highway #: 026 MT. HOOD Hwy						
90.21	100	2.57	S	500	11400	N
89.9	100	1.51	C	500	11400	N
89.68	100	2.13	S	200	11400	N
89.45	100	2.39	S	1200	11400	N
89.22	100	-2.28	C	200	11400	N
88.92	100	-2	C	500	11400	N
88.67	100	-1.1	S	500	11400	N
88.35	100	-3.12	C	600	11400	N
84.97	180	-1.86	C	800	26	N
84.69	180	-0.27	S	400	26	N
84.42	180	-1.85	S	200	26	N
84.04	180	-2.77	S	200	26	N
83.94	180	-4.43	C	400	26	N
83.81	180	-1.51	S	400	26	N
83.27	180	-3.58	C	500	26	N
82.91	180	-2.45	C	800	26	N
80.4	180	1.03	S	1000	26	N

The author obtained the automated speed enforcement information from the ODOT TransGIS Intelligent Transportation System (ITS) site. Figure 6.1 shows the ITS sites located along the Oregon state highways.

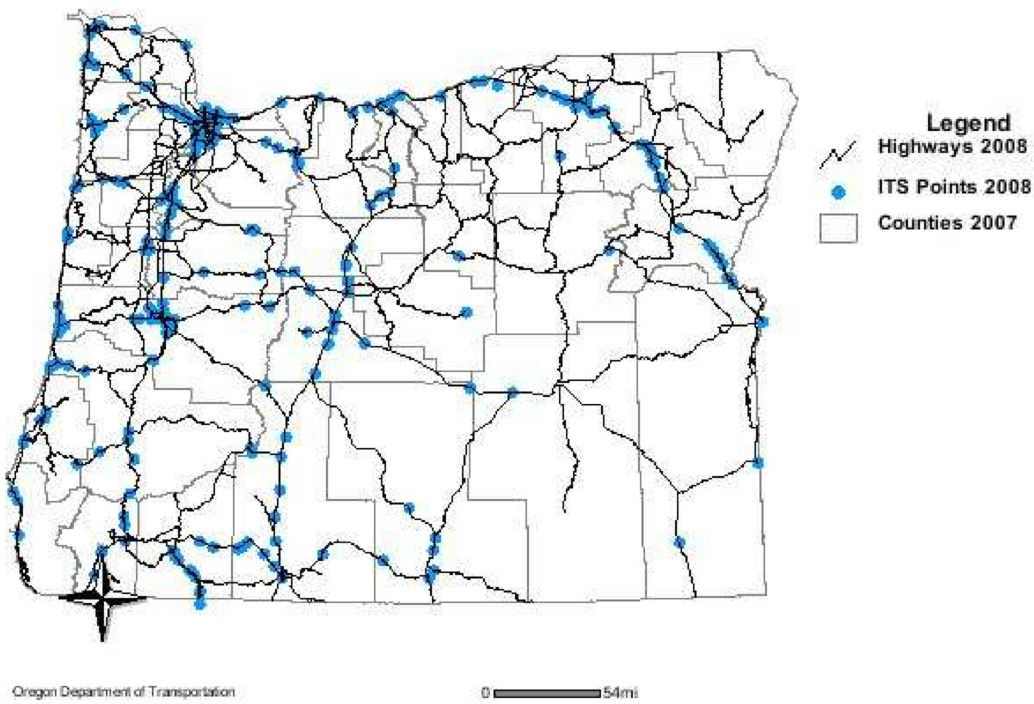


Figure 6.1: ITS Sites along State Highways

In Oregon, there is currently no available database which has information pertaining to the driveway density, the presence of centerline rumble strips, the presence of two-way left turn lanes, the roadside hazard rating, the side slope, and the lighting of roadways. Therefore, the authors used subjective judgment with assistance from the ODOT Digital Video Log to determine these variables. Figure 6.2 depicts an example video log view at MP 7.00 of the Oregon Coast Highway (HWY 009). The video log has images indicating surrounding features along state highways.

Figure 6.2: ODOT Digital Video Log

The author collected data including intersection lightings, intersection skew angle, intersection left turn lane, and intersection right turn lane from Google Earth images. To simplify the data collection process, when the skew angle was smaller than 10-degrees, the skew angle was assumed to be 0-degree. Figure 6.3 shows an example of the view of an intersection from Google Earth. In this intersection, there are four left-turn lanes on four approaches, and two right-turn lanes on major approaches. The skew angle is smaller than 10-degrees (about 8-degrees), so it was assumed to have an appropriate skew angle of 0-degrees.

Figure 6.3: Use of Google Earth for Intersection Characteristics Data

Finally, Table 6.4 lists the sources for the various data elements ultimately used for the final calibration effort.

Table 6.4: Resources of Characteristics Data

Data Elements	**Resources**
AADT of Major Road	ODOT Traffic Volumes and Vehicle Classification Report and Local Agencies
AADT of Minor Road	ODOT Traffic Volumes and Vehicle Classification Report , Local Agencies and AADT Estimate Model
Segment Length	Length of Homogenous Roadway Segment
Lane Width	ODOT State Highway Lane Report
Shoulder Width	ODOT State Highway Lane Report
Shoulder Type	ODOT State Highway Lane Report
Horizontal Curve Data	ODOT State Highway Horizontal Curve Report
Vertical Grades	ODOT State Highway Vertical Grade Report
Driveway Density	ODOT Digital Video Log
Centerline Rumble Strips	ODOT Digital Video Log
Passing Lanes	ODOT State Highway Lane Report
TWLTLs	ODOT Digital Video Log
Roadside Hazard Rating	ODOT Digital Video Log
Side Slope	ODOT Digital Video Log
Median Type and Width	ODOT State Highway Lane Report
Lighting	ODOT Digital Video Log (Roadway), Google Earth
Automated Speed Enforcement	ODOT TransGIS
Intersection Skew Angle	Google Earth
Intersection Left-Turn Lane	Google Earth
Intersection Right-Turn Lane	Google Earth

6.3 Summary of Data Collection

This section demonstrates the data collection methods and sources for the calibration effort. The data collection includes observed crash data and road characteristic data for the predictive models. With these two types of data, the author could then compute calibration factors for all facility types.

7.0 DATA ANALYSIS

This section illustrates the generation of the AADT estimation model, the observed crash data assignment, and the calibration process. In addition, the author reviews the method used to generate locally derived values.

7.1 AADT Estimation Model

The AADT for minor roads at intersection locations is a type of road characteristic data required for intersection safety assessment. However, many minor roads are maintained by local agencies and have limited available AADT data. Therefore, this type of data is often not available for intersection locations. Because the collection of all unavailable AADT data is impractical, the author generated a set of AADT estimation models based on characteristics of those sites which have available AADT data. With these models, the author could then estimate unavailable AADT data. The AADT estimation models were multiple linear regression models.

7.1.1 Response Variable and Independent Variables

The response variable for these estimation models was the AADT of the minor road. The author evaluated a variety of independent variables and finally found 12 variables which appeared to contribute to the estimation procedure (see Table 7.1).

Table 7.1: Candidate Independent Variables for Minor AADT Estimation Models

Variable	Description
CtPop	County population
CityPop	Population of nearest city
Income	Average per capita income of the region
Distance	Distance to the nearest freeway (miles)
MIA	Is the cross street a minor arterial? (1=yes, 0=no)
MAC	Is the cross street a major collector? (1=yes, 0=no)
CityLimit	Is the intersection located within a city limit? (1=yes, 0=no)
Right	Is a right-turn lane present on the minor road? (1=yes, 0=no)
RightCross	Does the major road have a right-turn lane? (1=yes, 0=no)
LandUse	Is the adjacent land developed? (1=yes, 0=no)
Centerline	Is a centerline present on the minor road? (1=yes, 0=no)
Edgeline	Does the minor road have striped edgelines? (1=yes, 0=no)

In Table 7.1, the first four independent variables are continuous variables. To minimize the unbalanced variance of these variables, the author transformed both the response and independent continuous variables to a log 10 configuration prior to the model regression.

7.1.2 Multicollinearity Issues

When models have two or more predictor variables, these variables may be highly correlated to each other. This statistical phenomenon is called multicollinearity. Because one important assumption of linear regression is that independent variables should not be correlated to each other, the author attempted to minimize the multicollinearity issue between variables. Therefore, before the model regression, all independent continuous variables were centered to relieve the multicollinearity problem (Mohamad, Sinha, Kuczek, & Scholer, 1998). By centering variables, all observations of these variables were subtracted from the mean of all observations.

In addition, the author used the variance inflation factor (VIF) to test if strong correlations existed between independent variables. Generally when the maximum VIFs for all variables is less than 10, there is no serious multicollinearity problem (Rawlings, Pantula, & Dickey, 1998). Table 7.2 depicts VIFs for all of the candidate independent variables. As shown in Table 7.2, VIFs for all independent variables were considerably less than 10 with the largest value of 1.66. As a result, no significant multicollinearity problem exists among the candidate independent variables.

Table 7.2: VIFs of Independent Variables

Variable	CtPop	CityPop	Income	Distance	MIA	MAC
VIF	1.576216	1.31081	1.197954	1.289462	1.409835	1.278494
Variable	CityLimit	Right	RightCross	LandUse	Centerline	Edgeline
VIF	1.28243	1.19889	1.266984	1.268892	1.434917	1.662607

After the model selection, the author then calculated actual Pearson's correlations between selected independent variables and did not find serious correlation issues.

7.1.3 Variable Selection

The author used Cp statistics to select the optimal variables combination from all possible combinations of 12 variables. To find this combination, the initial step is to use a statistical software package to automatically select one optimal model for each number of parameters (the intercept and variables). The author then developed a Cp plot to find the optimal number of parameters (see Figure 7.1). Figure 7.1 depicts the relationship between the Cp statistic of each optimal model the number of parameters, p. The line depicted in Figure 7.1 represents when Cp equals p. The final optimal model should have this characteristic of Cp equals p (Ramsey & Schafer, 2002). For a Cp value above the line, the model is biased. A Cp below the line suggests that the model includes unnecessary independent variables. To choose the final optimal model, the author selected the smallest p value where the Cp was smaller than p. Figure 7.1 indicates the desired model is selected when p equals 10. The optimal combination of predictor variables when p equals 10 included variables of Distance, MIA, MAC, CityLimit, Right, RightCross, LandUse, Centerline and Edgeline.

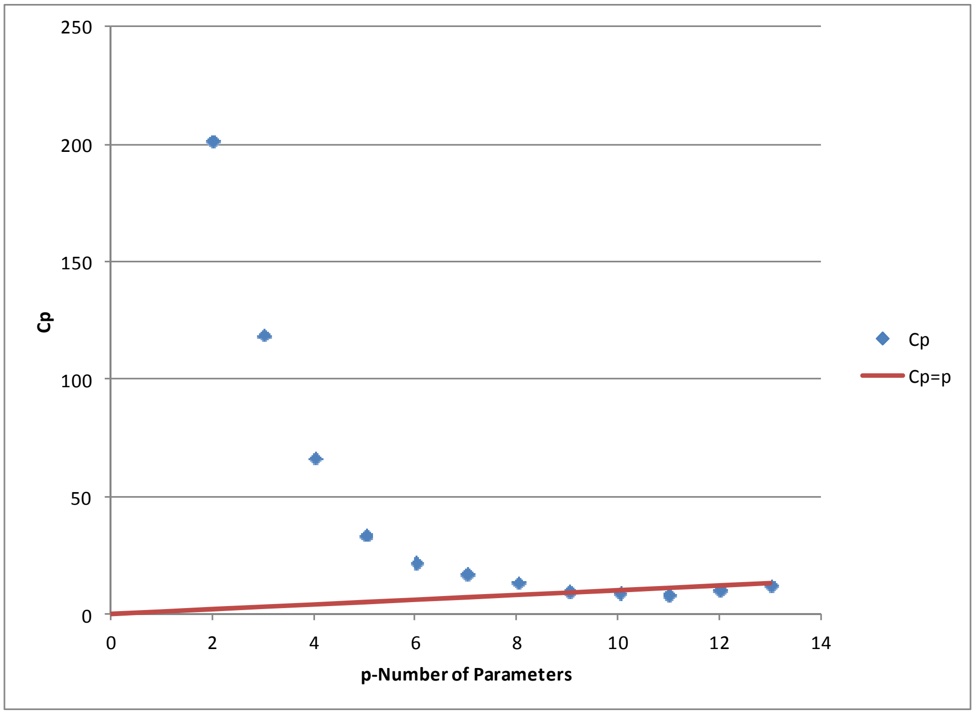


Figure 7.1: Cp Plot

7.1.4 Model Regression

The author found that MR4SG requires a separate model. As a result, the author generated two AADT estimation models. Model 1 estimated the AADT for minor roads of all intersection types except for MR4SG. Model 2 estimated the AADT for minor roads of MR4SG. Table 7.3 depicts the regression results for these two models.

Table 7.3: Regression for Two Models

Models:	**Model 1 [Applies to Intersection R3ST, R4ST,R4SG, MR3ST, and MR4ST]**		**Model 2 [Applies to Intersection MR4SG]**	
R-Square:	0.6231		0.6395	
Variable Name	Value	Pr (>|t|)	Value	Pr (>|t|)
Intercept	2.0281	0.0000	2.0246	0.0000
Distance (transformed and centered)	-0.1120	0.0136	-0.1064	0.0170
MIA	0.6810	0.0000	0.6634	0.0000
MAC	0.4148	0.0000	0.4132	0.0000
CityLimit	0.1391	0.0732	0.1427	0.0580
Right	0.1761	0.0266	0.1987	0.0093
RightCross	0.2060	0.0036	0.2073	0.0025
LandUse	0.2125	0.0001	0.2229	0.0000
Centerline	0.3028	0.0001	0.2988	0.0001
Edgeline	0.1268	0.0451	0.1381	0.0281

These two models are shown in Equation 6-2 and Equation 6-3.

Model 1:

$$log_{10}AADT = 2.0281 - 0.112 \times (log_{10}Distance - 1.175) + 0.681MIA + 0.4148MAC + 0.1391CityLimit + 0.1761Right + 0.2060RightCross + 0.2125LandUse + 0.3028Centerline + 0.1268Edgeline \quad (6\text{-}2)$$

Model 2:

$$log_{10}AADT = 2.0246 - 0.1064 \times (log_{10}Distance - 1.178) + 0.6634MIA + 0.4132MAC + 0.1427CityLimit + 0.1987Right + 0.2073RightCross + 0.2229LandUse + 0.2988Centerline + 0.1381Edgeline \quad (6\text{-}3)$$

The values of “1.174634” in Model 1 and “1.177515” in Model 2 result from the log10 transformed distance.

R-square values of these two models are greater than 0.6, suggesting that these two models could effectively indicate AADTs of minor roads. In addition, all values of parameters have expected signs and there are no strong correlations between variables. Therefore, these two models could be used to estimate AADT of minor roads in Oregon.

7.2 Crash Assignment

Since crashes that have occurred on highways could be either intersection related or roadway related, it is important to have a reasonable method to assign crashes. The roadway crash assignment and the intersection crash assignment are similar in theory. Methods of assigning crashes to roadway sites or intersection sites are stated separately below.

7.2.1 Assigning Crashes to Roadway Sites

For each roadway type, the author recorded all crashes that occurred along the selected roadway segments during the three year study period (2004-2006). He then analyzed each crash to determine if it should be assigned as roadway related. The steps of this analysis are shown in the order of preference as follows:

1. If the crash data indicated that the crash occurred at an intersection, the crash is not assigned to the segment.
2. If the crash is indicated to be intersection related, the crash is not assigned to the segment.
3. If the crash is indicated to be driveway related, the crash is assigned to the segment.
4. If the crash is a rear-end crash and the crash occurred at an intersection approaching leg, then the crash is not assigned to the segment.
5. All other crashes are assigned to the segment.

After all crashes were assigned, the author next counted all qualified roadway segment crashes, and used this total value as the total number of observed crashes for the particular roadway type.

7.2.2 Assigning Crashes to Intersections

For each intersection type, the author recorded all crashes at the selected intersections and their legs (250 ft from the center of intersections) during the three year study period (2004-2006). He then analyzed each crash around an intersection to determine if that crash was related to that intersection. The steps of the analysis are shown in the order of preference as follows:

1. If the crash data indicated that the crash occurred at the intersection, the crash is assigned to that intersection.
2. If the crash is indicated to be intersection related, the crash is assigned to that intersection.
3. If the crash is indicated to be driveway related, the crash is not assigned to that intersection.
4. If the crash is a rear-end crash and the crash occurred at the intersection approach, then the crash is assigned to that intersection.
5. All other crashes are not assigned to that intersection.

After all crashes were assigned, the author counted all qualified intersection related crashes, and used the total value as the total number of observed crashes for the particular intersection type.

7.3 Homogenous Roadway Segments

The HSM requires that each roadway segment site should be divided into homogenous segments (*AASHTO, 2010*). Since road characteristics may vary frequently along each segment, the HSM recommends a minimum homogenous segment to be 0.1 miles. However, it is time consuming for researchers to weight average CMFs due to the characteristics changes within the 0.1 miles segment. In Oregon, the ODOT state highway inventory reports provided characteristics data for average 0.01 MP of all state highways. Therefore, instead of dividing segment sites into homogenous segments, in this project all sites were first divided into 0.01 miles segments which are the minimum measure by ODOT, and then these 0.01 miles segments were combined into homogenous segments of which the minimum length was 0.1 miles. For the minimum homogenous segment, when characteristics vary within the segment, CMFs of all 0.01 miles compositive segments were averaged in order to weight average effects of characteristics changes along the segment. The total predictive crash frequency of all combined homogenous segments is the total predictive crash frequency of the site.

7.4 Predicted Crash Calculation

In this section, the author reviews the predicted crash calculation process and then uses an example for further explanation.

7.4.1 Predicted Crash Calculation Process

To calculate the unadjusted predicted crash frequency of each homogeneous segment or intersection, an analyst should calculate the number of crashes under the base condition using the SPF included in the HSM. For example, the base conditions for a rural two-lane, two-way road segment are 12 ft lane width, 6 ft paved shoulder width, a roadway hazard rating which is 3, 5 driveways per mile (A roadway hazard rating, scaling from 1 to 7, represents roadside design features such as sideslope and clear zone width), level vertical condition, no horizontal curves, no supplemental lanes, no rumble strips, no lighting, and no automated speed enforcement. N_{spf} is the value of predicted total crash frequency for the base condition as calculated using the SPF equation.

The next step is multiplying N_{spf} by all CMFs that represent non-base condition. When any feature of the site adheres to the base condition, the associated CMF equals 1.0. When the feature does not achieve base conditions, it is expected to have a CMF value that is not equal to 1.0. If the feature would result in a decrease in predicted crashes compared with the base condition, then the CMF should have a value smaller than 1.0. The CMF is a multiplicative value so multiplying by 1.0, therefore, does not influence total predicted crashes.

7.4.2 Example of Predicted Crash Calculations

An example of a MRU site (Site 3) on Hwy 35 [from MP 15.93 to MP 17.93] can help to demonstrate predicted crash calculation process. In this example, the study year is 2005. Road characteristic data for part of this segment (MP 16.85 to MP 17.11) are shown in Table 7.4. In Table 7.4, the location of MP 16.85 is the end of previous homogenous roadway segment (Segment 4). A new segment (Segment 5) should start at this location. The table indicates that at MP 16.89, the side slope for one side varies from 1:2 to 1:7. The Segment 5 should end at MP 16.89. However, the minimum segment length is 0.1 miles. The Segment 5 should continue until the length reaches the minimum length. Therefore, Segment 5 is from MP16.85 to MP 16.95 with the length of 0.1 miles, and the next homogenous segment in this site is from MP16.95 to MP 17.11 (Segment 6). There are a total of 11 homogenous segments for Site 3.

Table 7.5 shows the part of the predicted crash calibration spreadsheet for Site 3 of MRU segments. The predicted number of crashes for the base condition are 0.235and 0.376 for segments 5 and 6 respectively. The CMFs are averaged for each segment. After the CMFs are applied, the unadjusted predicted number of crashes for Segment 5 is 0.238, while this value is 0.387 for Segment 6. After calculating the unadjusted predicted crash frequencies for all homogenous segments, the total predicted number of crashes for this site can be determined as the sum of all unadjusted predicted crash frequencies. The total predicted crash frequency for site 3 is 5.416.

Table 7.4: Characteristics Data Spreadsheet of Roadway Segments

Site NO	Segment No	Hwy NO	Beg MP	End MP	Length (mi)	AADT (2005)	Lane Width (ft)				Shoulder Width (ft)		Shoulder Type	Side Slope (1:X)		Light	Automated Speed Enforcement
							1	2	3	4	1	2		1	2		
	⋮																
3	5	35	16.85	16.86	0.01	7600	12	12	12	12	10	10	paved	7	2		
3	5	35	16.86	16.87	0.01	7600	12	12	12	12	10	10	paved	7	2		
3	5	35	16.87	16.88	0.01	7600	12	12	12	12	10	10	paved	7	2		
3	5	35	16.88	16.89	0.01	7600	12	12	12	12	10	10	paved	7	2		
3	5	35	16.89	16.9	0.01	7600	12	12	12	12	10	10	paved	7	6		
3	5	35	16.9	16.91	0.01	7600	12	12	12	12	10	10	paved	7	6		
3	5	35	16.91	16.92	0.01	7600	12	12	12	12	10	10	paved	7	6		
3	5	35	16.92	16.93	0.01	7600	12	12	12	12	10	10	paved	7	6		
3	5	35	16.93	16.94	0.01	7600	12	12	12	12	10	10	paved	7	6		
3	5	35	16.94	16.95	0.01	7600	12	12	12	12	10	10	paved	7	6		
					SUM	Average											
					0.1	7600											
3	6	35	16.95	16.96	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	16.96	16.97	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	16.97	16.98	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	16.98	16.99	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	16.99	17	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17	17.01	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.01	17.02	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.02	17.03	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.03	17.04	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.04	17.05	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.05	17.06	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.06	17.07	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.07	17.08	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.08	17.09	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.09	17.1	0.01	7600	12	12	12	12	6	6	paved	7	6		
3	6	35	17.1	17.11	0.01	7600	12	12	12	12	6	6	paved	7	6		
					SUM	Average											
					0.16	7600											
3	⋮	Note: Site 3 is from MP 15.93 to MP 17.93. There are 11 homogenous segments. This table shows examples of segment 5 and segment 6															

Table 7.5: Unadjusted Predicted Crash Frequency Calculation Spreadsheet

Site NO	Segment No	Hwy NO	Beg MP	End MP	L (mi)	AADT (2005)	N_{spf}	CMFs					$N_{predict}$
								Lane Width	Shoulder Width and Type	Side Slope	Lighting	Automated Speed Enforcement	
	⋮												⋮
3	5	35	16.85	16.86	0.01	7600		1	0.96	1.09	1	1	
3	5	35	16.86	16.87	0.01	7600		1	0.96	1.09	1	1	
3	5	35	16.87	16.88	0.01	7600		1	0.96	1.09	1	1	
3	5	35	16.88	16.89	0.01	7600		1	0.96	1.09	1	1	
3	5	35	16.89	16.9	0.01	7600		1	0.96	1.03	1	1	
3	5	35	16.9	16.91	0.01	7600		1	0.96	1.03	1	1	
3	5	35	16.91	16.92	0.01	7600		1	0.96	1.03	1	1	
3	5	35	16.92	16.93	0.01	7600		1	0.96	1.03	1	1	
3	5	35	16.93	16.94	0.01	7600		1	0.96	1.03	1	1	
3	5	35	16.94	16.95	0.01	7600		1	0.96	1.03	1	1	
					SUM	Average							
					0.1	7600	0.23	1	0.96	1.05	1	1	0.238
3	6	35	16.95	16.96	0.01	7600		1	1	1.03	1	1	
3	6	35	16.96	16.97	0.01	7600		1	1	1.03	1	1	
3	6	35	16.97	16.98	0.01	7600		1	1	1.03	1	1	
3	6	35	16.98	16.99	0.01	7600		1	1	1.03	1	1	
3	6	35	16.99	17	0.01	7600		1	1	1.03	1	1	
3	6	35	17	17.01	0.01	7600		1	1	1.03	1	1	
3	6	35	17.01	17.02	0.01	7600		1	1	1.03	1	1	
3	6	35	17.02	17.03	0.01	7600		1	1	1.03	1	1	
3	6	35	17.03	17.04	0.01	7600		1	1	1.03	1	1	
3	6	35	17.04	17.05	0.01	7600		1	1	1.03	1	1	
3	6	35	17.05	17.06	0.01	7600		1	1	1.03	1	1	
3	6	35	17.06	17.07	0.01	7600		1	1	1.03	1	1	
3	6	35	17.07	17.08	0.01	7600		1	1	1.03	1	1	
3	6	35	17.08	17.09	0.01	7600		1	1	1.03	1	1	
3	6	35	17.09	17.1	0.01	7600		1	1	1.03	1	1	
3	6	35	17.1	17.11	0.01	7600		1	1	1.03	1	1	
					SUM	Average							
					0.16	7600	0.37	1	1	1.03	1	1	0.387
3	⋮												⋮
												SUM:	5.416

7.5 Calculation of Calibration Factors

Following the calculation for the total observed crashes and the total unadjusted predicted crashes of all sites, the author could then calculate the associated calibration factor. The calibration factor is calculated as follows:

$$C = \frac{\sum_{allsites} N_{observed}}{\sum_{allsites} N_{predicted(unadjusted)}} \tag{6-4}$$

Where:

$N_{observed}$ = observed crash frequency of each site

$N_{predicted(unadjusted)}$ = unadjusted predicted crash frequency of each site

C = calibration factor

Based on the example shown in Section 7.4.2, the total predicted crash frequency for site 3 is 5.416 for the year of 2005. The total observed roadway crash frequency for this site is 5 during the year 2005. Therefore the calculation of the calibration factor for this site with the study period of 2005 is shown as follows:

$$C_{Site\ 3\ (2005)} = \frac{5}{5.416} = 0.92 \tag{6-5}$$

The calibration factor of 0.92 is an example of how to calculate calibration factors; however, the actual calibration factor needs to be calculated based on the HSM calibration process requirement.

7.6 Development of Locally Derived Values

The HSM default values include the collision type distribution, the severity proportion, and the nighttime crash proportion. These default values were developed for a subset of states in the United States. Therefore, these default values may not represent crash characteristics in Oregon and developing Oregon locally derived values may make the calibration results more reliable. To develop these values, the author analyzed the crash data of all state highways in Oregon. The author then generated two types of locally derived values: (1) Each design year has its own locally derived values which are derived from crash data of that year; (2) Average locally derived values which are derived from crash data of all three years.

In this section of the data analysis overview, the authors illustrated the method to generate the AADT estimation model, the crash assignment approaches, calibration calculation methods, and the development of locally derived values. The next section reviews the calibration results.

8.0 CALIBRATION RESULTS

In this section, the author reviews the results for the calibration project. Calibration results include the calibration factors using HSM default proportions for all facility types, and statistical analysis results of the comparison between using HSM default proportions and using two types of locally derived values in the calibration process. Finally, the author developed calibration factors for fatal and injury crash types.

8.1 Calibration Factors Based on HSM Default Proportions

Calibration factors based on HSM default proportions are shown in Table 8.1. For each facility type, the table provides a calibration factor based on three years' crash data and calibration factors based on each year's crash data. Calibration factors are also depicted in Figure 8.1.

Table 8.1: Estimated Calibration Factors for Oregon (HSM default crash proportions)

Facility Type	n	Observed (O) and Predicted (P) Crashes								Calibration Factor			
		2004		2005		2006		2004-2006		2004	2005	2006	2004-2006
		O	P	O	P	O	P	O	P	C_{2004}	C_{2005}	C_{2006}	C_{04-06}
SEGMENTS													
Rural Two Lane													
R2	75	123	180	139	176	132	177	394	533	0.68	0.79	0.75	0.74
Rural Multilane													
MRU	50	111	337	138	332	115	334	364	1003	0.33	0.42	0.34	0.36
MRD	19	17	25	15	25	26	25	58	75	0.69	0.60	1.03	0.78
INTERSECTIONS													
Rural Two Lane													
R3ST	200	31	115	43	113	34	114	108	342	0.27	0.38	0.30	0.32
R4ST	200	67	220	59	216	78	216	204	652	0.31	0.27	0.36	0.31
R4SG	25	38	99	51	99	53	102	142	300	0.38	0.51	0.52	0.47
Rural Multilane													
MR3ST	100	16	80	10	78	11	78	37	236	0.20	0.13	0.14	0.16
MR4ST	107	48	150	58	149	72	148	178	446	0.32	0.39	0.49	0.40
MR4SG	34	51	352	49	352	57	349	157	1053	0.14	0.14	0.16	0.15

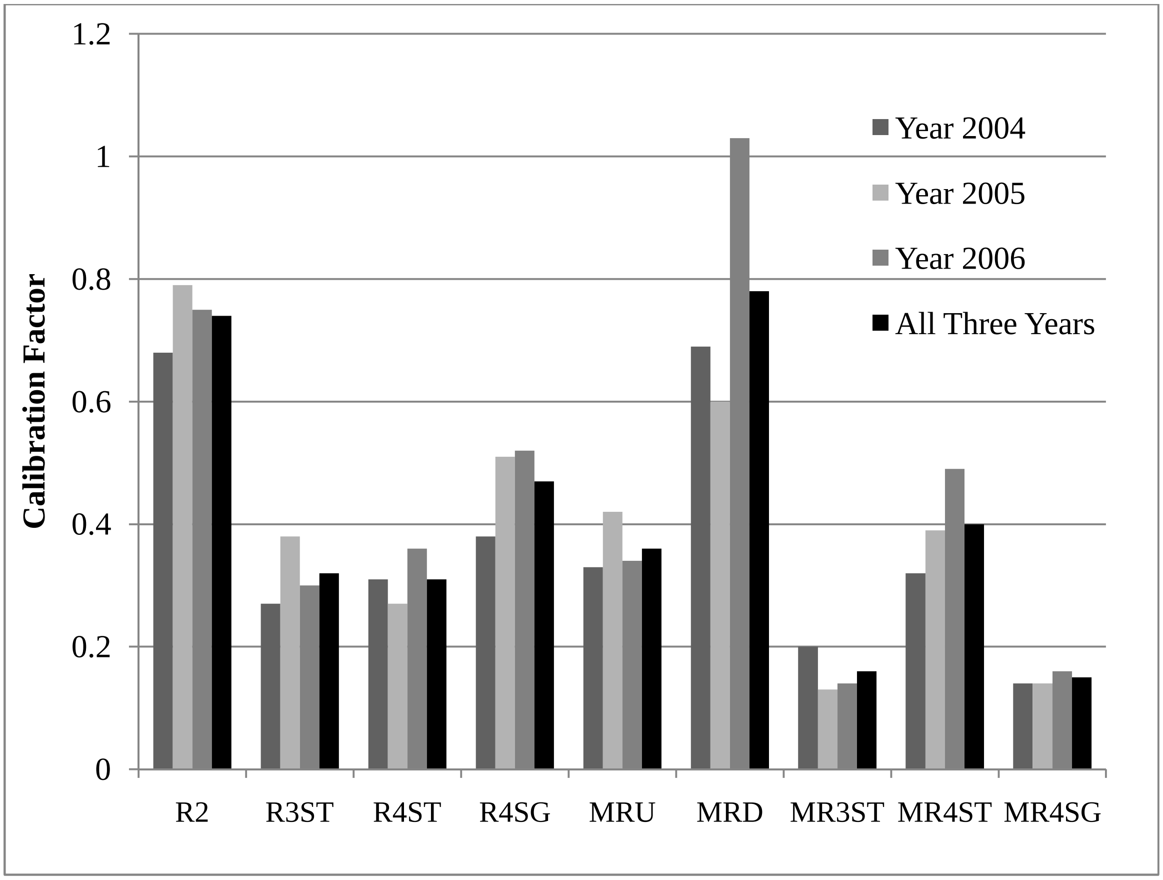


Figure 8.1: Calibration Factors by Design Years

As shown in Table 8.1 and Figure 8.1, for all facility types, the calibration factors based on three years' crash data are less than 1.00. Reasons of low calibration factors will be explained in Section 8.4. MR4SG has the lowest calibration factor with a value of 0.15. The low calibration factor of MR4SG is because that current HSM does not provide CMFs for the predictive model of MR4SG and the predicted crash frequency for this type is much higher than expected. Except for MRD, calibration factors of most facility types are consistently in the same level over three years. The reason for the inconsistent distribution of calibration factors for MRD is due to the very limited availability of sites for this facility type and the large variance within the small sample size.

8.2 Locally Derived Values Results

Based on the locally derived value generation method in Section 7.6, the author developed two types of locally derived values: (1) locally overall derived values (values are developed for all three years); and (2) locally individual derived values (values are developed for each design year). Table 8.2, Table 8.3, and Table 8.4 depict example locally derived values (overall) of rural two-lane, two-way roads. All locally overall and individual derived values of all facility types will be presented in Appendix B.

Table 8.2: HSM-Default Collision Distributions versus Oregon Distribution (Three Years Crash Data) (Rural Two-Lane, Two-Way Roads)

Percentage of total roadway segment crashes by crash severity level						
Collision type	HSM-Provided Values*			Locally Overall Derived Values		
	Total fatal and injury	Property damage only	TOTAL (all severity levels combined)	Total fatal and injury	Property damage only	TOTAL (all severity levels combined)
SINGLE-VEHICLE CRASHES						
Collision with animal	3.8	18.4	12.1	3.1	12.0	7.2
Collision with bicycle	0.4	0.1	0.2	0.6	0.0	0.3
Collision with pedestrian	0.7	0.1	0.3	0.8	0.0	0.4
Overturned	3.7	1.5	2.5	8.6	3.8	6.4
Ran off road	54.5	50.5	52.1	47.1	39.1	43.5
Other single-vehicle crash	0.7	2.9	2.1	1.7	1.3	1.5
Total single-vehicle crashes	63.8	73.5	69.3	62.0	56.2	59.3
MULTIPLE-VEHICLE CRASHES						
Angle collision	10	7.2	8.5	0.8	0.7	0.8
Head-on collision	3.4	0.3	1.6	5.8	1.0	3.6
Rear-end collision	16.4	12.2	14.2	18.8	21.4	20.0
Sideswipe collision	3.8	3.8	3.7	4.4	7.1	5.6
Other multiple-vehicle collision	2.6	3.0	2.7	8.2	13.5	10.6
Total multiple-vehicle crashes	36.2	26.5	30.7	38.0	43.8	40.7
TOTAL CRASHES	100.0	100.0	100.0	100.0	100.0	100.0

**Source: AASHTO, 2010*

Table 8.3: HSM-Default Crash Severity Levels versus Oregon Levels (Three Years Crash Data) (Rural Two-Lane, Two-Way Roads)

Crash severity level	**Percentage of total roadway segment crashes**	
	HSM-Provided Values*	**Locally Overall Derived Values**
Fatal	1.3	3.1
Incapacitating Injury	5.4	7.7
Nonincapacitating Injury	10.9	25.1
Possible Injury	14.5	18.0
Total Fatal Plus Injury	32.1	54.0
Property Damage Only	67.9	46.0
TOTAL	100.0	100.0

**Source: AASHTO, 2010*

Table 8.4: HSM-Default Nighttime Proportions versus Oregon Proportions (Three Years Crash Data) (Rural Two-Lane, Two-Way Roads)

	HSM Default Values*		
Roadway Type (2U)	Proportion of total nighttime crashes by severity level		Proportion of crashes that occur at night
	Fatal and Injury p_{inr}	PDO p_{pnr}	p_{nr}
	0.382	0.618	0.37
	Locally Overall Derived Values		
	Proportion of total nighttime crashes by severity level		Proportion of crashes that occur at night
	Fatal and Injury p_{inr}	PDO p_{pnr}	p_{nr}
	0.54	0.46	0.28

**Source: AASHTO, 2010*

To find if locally derived values are more appropriate for the calibration process in Oregon, the author used statistical methods to compare the differences in calibration factors between using HSM default proportions and two types of locally derived values. Details will be presented in Section 8.3. In additions, as shown in Table 8.3, the PDO crashes have a much smaller proportion than the HSM default proportions. Analysis of the Oregon crash severity proportion will be presented in Section 8.4 and Section 8.5.

8.3 HSM Default Proportions versus Locally Derived Values

It is important to understand if there is difference in total predicted crash frequencies of all sites between using default proportions and locally derived proportions. There are two methods in using locally derived proportions. The first one is using the locally individual derived values based on each year. The second one is using the locally overall derived values based on three years. Therefore, the author constructed three paired t tests to find differences between these three methods. Results are shown in Table 8.5, Table 8.6 and Table 8.7.

As shown in Table 8.5, Table 8.6 and Table 8.7, MR4SG is not presented in the comparison. That is because the MR4SG SPF does not incorporate CMFs and locally derived proportions have no effect in changes of the predicted crashes for MR4SG. For all three comparisons, p-values are larger than 0.05, and there is no significant difference between three methods. Therefore, in Oregon, the application of locally derived values will result in a statistically significant difference in the calibration factor results compared with using the HSM default proportions. If agencies do not have available data to generate locally derived values, they can use default values confidently.

Table 8.5: 1st Comparison: HSM Default Proportions versus Locally Individual Derived Proportions

Facility Type	HSM Default Proportions		Locally Individual Derived Proportions		Outputs
	Total Crashes	Sample size	Total Crashes	Sample size	
R2	532.82	75	527.153	75	p-value
R3ST	342.149	200	343.394	200	0.3027
R4ST	651.542	200	656.174	200	T
R4SG	299.96	25	317.506	25	-1.1124
MRU	1003.121	50	997.245	50	df
MRD	74.772	19	74.973	19	7
MR3ST	235.952	100	238.924	100	Confidence Interval
MR4ST	446.093	107	455.363	107	(-9.50,3.42)

Table 8.6: 2nd Comparison: HSM Default Proportions versus Locally Overall Derived Proportions

Facility Type	**HSM Default Proportions**		**Locally Overall Derived Proportions**		Outputs
	Total Crashes	**Sample size**	**Total Crashes**	**Sample size**	
R2	532.82	75	528.812	75	p-value
R3ST	342.149	200	343.523	200	0.3216
R4ST	651.542	200	655.012	200	T
R4SG	299.96	25	317.508	25	-1.0665
MRU	1003.121	50	995.816	50	df
MRD	74.772	19	75.01	19	7
MR3ST	235.952	100	239.162	100	Confidence Interval
MR4ST	446.093	107	454.58	107	(-9.26,3.50)

Table 8.7: 3rd Comparison: Locally Individual Derived Proportions vs Locally Overall Derived Proportions

Facility Type	**Locally Individual Derived Proportions**		**Locally Overall Derived Proportions**		**Outputs**
	Total Crashes	**Sample size**	**Total Crashes**	**Sample size**	
R2	527.153	75	528.812	75	p-value
R3ST	343.394	200	343.523	200	0.6486
R4ST	656.174	200	655.012	200	T
R4SG	317.506	25	317.508	25	0.476
MRU	997.245	50	995.816	50	df
MRD	74.973	19	75.01	19	7
MR3ST	238.924	100	239.162	100	Confidence Interval
MR4ST	455.363	107	454.58	107	(-0.65,0.98)

8.4 Explanation of Low Calibration Factors

As shown in Section 8.1, Oregon has experienced very low calibration factors for the HSM predictive methods. An initial interpretation of these low values is that it is safer to travel in Oregon. However, there might be other issues which may contribute to the low ratios. The State of Oregon has a crash reporting process that may explain these low calibration values.

The State of Oregon is a self-reporting state. In other words, if a crash happens with no injuries, the drivers are typically responsible for reporting the crash. The reporting threshold is that a crash results in death, injury, more than $1,500 damage to their vehicles, or more than $1,500 damage and towing of another vehicle. Many other states have much lower crash reporting thresholds. For example, the State of Washington has a $700 PDO reporting crash threshold while the threshold in the State of California is $750. The difference in the crash reporting threshold may contribute to the assumption that many qualified PDO crashes in Oregon were not reported. However, if the same crash occurred in Washington or California, the crash will be reported. Therefore, Oregon may appear to have fewer PDO crashes and the total observed crash frequency of each site is lower than expected. The reporting bias of PDO crashes is a possible reason of the low calibration factors in Oregon.

The crash reporting bias can be further explained by comparing the crash severity level between the HSM default proportions and the Oregon locally derived values. The HSM default proportions of roadway segment types were developed in the State of Washington, while the State of California provided the HSM default proportions of intersection types. As shown in Table 8.3, compared with the HSM default proportions, Oregon has a much lower proportion for the PDO crashes.

8.5 Calibration Factors: Total Crashes versus Fatal and Injury Crashes

Since the severity levels are significantly different between default proportions and locally derived values. The author was interested in looking for calibration factors for fatal plus injury crashes. Also, because the reporting for fatal plus injury crashes might be better than the reporting for PDOs crashes, predictive methods for fatal plus injury crashes might provide a better estimate of transportation safety in Oregon. Therefore, the author calculated calibration factors for fatal plus injury crashes. The bottom two lines of Table 8.8 show the comparison between calibration factors for total crashes and fatal plus injury crashes (two-way, two-lane rural roads).

Table 8.8: Calibration Comparison for Total Crashes versus Fatal plus Injury (Rural Two-Lane, Two-Way Roads) Using HSM-Proportional Values

Rural Two-Lane, Two-Way Facility	**R2**	**R3ST**	**R4ST**	**R4SG**
Sample Size (Sites)	75	200	200	25
Observed Crashes (Total for 2004 to 2006)	394	108	204	142
Observed Crashes (Fatal and Injury)	196	58	135	73
Predicted Crashes (Total for 2004 to 2006)	533	342	652	300
Predicted (Adjusted by Locally Proportions)	171	142	281	108
Calibration Factor (Total)	0.74	0.32	0.31	0.47
Calibration Factor (Fatal and Injury)	1.15	0.41	0.48	0.67

Table 8.8 indicates that for rural two-lane, two-way roads, calibration factors for fatal and injury crashes are larger than calibration factors for total crashes. This finding helps to confirm the previous observation that PDO crashes are less reported in Oregon, especially for rural two-lane, two-way roads.

Table 8.9: Calibration Comparison for Total Crashes versus Fatal plus Injury (Rural Multilane Highways) Using HSM-Proportional Values

Rural Multilane Facility	**MRU**	**MRD**	**MR3ST**	**MR4ST**	**MR4SG**
Sample Size (Sites)	50	19	100	107	34
Observed Crashes (Total for 2004 to 2006)	364	58	37	178	157
Observed Crashes (Fatal and Injury)	153	25	20	96	76
Predicted Crashes (Total for 2004 to 2006)	1003	75	236	446	1053
Predicted (Using SPFs for fatal and injury)	579	37	89	199	452
Calibration Factor (Total)	0.36	0.78	0.16	0.40	0.15
Calibration Factor (Fatal and Injury)	0.26	0.68	0.23	0.48	0.17

Table 8.9 shows the comparison between calibration factors for total crashes and fatal plus injury crashes for rural multilane highways. However, for rural multilane highways, the results do not show a trend of changes in calibration factors.

8.6 Summary

In this section, the author has identified the calibration factors of all facility types based on the HSM default proportions. Locally derived values were also developed, however results did not indicate that the application of locally derived values would change the calibration results. In addition, since almost all calibration factors have very low values, the author analyzed the crash reporting issue and explained the low ratios in Oregon. Furthermore, the author developed calibration factors for fatal and injury crashes are developed. Although the calibration factors for fatal and injury crashes did not increase for rural multilane highways, the author found a substantial increase in the ratio for rural two-lane, two-way roads.

9.0 FUTURE CALIBRATION SAMPLE SIZE DETERMINATION METHOD

As stated in previous sections, the HSM has a sample size requirement for the calibration process. For each facility type, researchers are required to select at least 30 to 50 sites. After that, more sites need to be selected until all sites of each facility type can represent 100 crashes per year. If specific facility type has fewer than 30 sites, all available sites should be included in the calibration sample.

During the calibration project for the State of Oregon, the author found the HSM sample size determination plan is impractical for some facility types. As a result, details of limitations of the HSM sample size requirement will be stated in Section 9.1. In addition, the author found a statistical method to better estimate the calibration sample size. Analysis and a sample application of this new method will be illustrated Section 9.3 and Section 9.4.

9.1 Limitations of HSM Sample Size Determination Plan

During the data collection process, the author found that the target of 100 crashes per year was hard to achieve for some facility types, though the sample has been increased. Many sites do not have observed crashes. This observation occurs frequently at low volume rural intersections. Because the data collection for each site is time consuming, it is impractical to meet the sample size requirement for all facility types. Therefore, for the Oregon calibration project, the author used practical calibration sample sizes based on the author’s judgment and the crash history. Actual sample size for each facility type can be found in Table 8.1. However, after the calibration project, the author made an estimation of the required sample size if the HSM sample size requirement cannot be achieved. Results are depicted in Table 9.1. The required sample size for each facility type is determined based on the average crash frequency per year of each site. For example, for R2 segments, the average crash frequency per year is 1.751. To meet the requirement of 100 crashes per year, there should be at least about 57 sites. After rounding up to the nearest 5 sites, the author determined that the required sample size should be 60 sites for R2 segments.

Table 9.1: Estimation of HSM Required Sample Sizes for Oregon Facility Types

Facility Type		Total Observed Crash Frequency (Three Years)	Actual Sample Size	Average Crash Frequency per Site (Each Year)	Required Sample Size
SEGMENTS					
Rural Two Lane Two Way					
R2	2-lane Undivided	394	75	1.751	60
Rural Multilane					
MRU	4-lane undivided	364	50	2.427	45
MRD	4-lane dividied	40	19	0.702	145
INTERSECTIONS					
Rural Two Lane Two Way					
R3ST	3-leg, minor STOP	108	200	0.180	560
R4ST	4-leg, minor STOP	204	200	0.340	295
R4SG	4-leg, signalized	142	25	1.893	55
Rural Multilane					
MR3ST	3-leg, minor STOP	37	100	0.123	815
MR4ST	4-leg, minor STOP	178	107	0.555	185
MR4SG	4-leg, signalized	157	34	1.539	65

Table 9.1 indicates that to meet the HSM requirement intersections require very large sample sizes. For example, MR3ST requires 815 sites. These sample sizes are impractical for a calibration project. Although the total number of available sites may be smaller than the required sample size, sampling all available sites is still very time-consuming for researchers. It is true that a target of a specific number of crashes can force researchers to increase the sample size and reduce the sampling error. However such requirements may create difficulties for the calibration process. In addition, the target of 100 crashes per year lacks a clear statistical basis. To estimate the required sample size using statistical methods, researchers need to consider the population variance, the total population size, the targeted confidence level, the required margin of error, and other related features. For

some states that experience high average crash frequency per site and large variance in crash characteristics between sites, the HSM required sample size may not provide enough calibration precision. On the other hand, for other states which experience very low crash frequency per site, the sample size requirement may be too conservative for the calibration project. Therefore, the target of 100 crashes per year is not the optimal boundary to determine the sample size. A new method using statistic approaches is needed to have a better estimation of the required sample size based on the local crash data.

9.2 A New Sample Size Determination Method

After the calibration project, the author did further analysis of the calibration project and identified a statistical method to calculate the required sample size for each facility type. In this method, the calibration factor can be interpreted as the ratio of the total observed crash frequency and the total predicted crash frequency. For each facility type, the author denotes the three years total predicted crash frequency for each site as x_i, as well as the three year total observed crash frequency for each site as y_i. Then the calibration factor for this facility type is shown in Equation 9-1 and n is the total number of sites.

$$C = \frac{\sum_1^n y_i}{\sum_1^n x_i} \tag{9-1}$$

As shown in Equation 9-1, the calibration factor C is the estimate of the ratio of two variables, y and x. The author defined a residue variable e_i, which is the ith residual from fitting the line $y = Cx$ (see Equation 9-2). By conducting a pilot study, the sample variance s_e^2 of the residuals e_i can be determined using Equation 9-3.

$$e_i = y_i - Cx_i \tag{9-2}$$

$$s_e^2 = \frac{1}{n' - 1} \sum_{i \in S} e_i^2 \tag{9-3}$$

Where $n'$is the number of sites for the pilot study.

With the calculated sample variance of the residuals when a specific number of sites was sampled, the author could determine the variance of the calibration factor C using Equation 9-4 (*Sharon, 2009*).

$$\hat{V}(C) = \left(1 - \frac{n}{N}\right)\frac{S_e^2}{n\bar{x}^2} \tag{9-4}$$

Where:

N = the total population size;

n = the sample size;

$\bar{x}$ = the average predicted crash frequency for each site.

With specific level of confidence α, the margin of error e was determined using Equation 9-5. After combining Equation 9-4 and Equation 9-5, the author can calculate the required sample size n using Equation 9-6 with the level of confidence α and the margin of error e.

$$e = Z_{\frac{\alpha}{2}}\sqrt{\hat{V}(C)} \tag{9-5}$$

$$n = \frac{1}{\frac{e^2\bar{x}^2}{Z_{\frac{\alpha}{2}}{}^2 S_e^2} + \frac{1}{N}} \tag{9-6}$$

With the sample size calculated in Equation 9-6, the author can estimate how many sites are required to sample for each facility type. In summary, basic steps to determine the required sample size can be illustrated as follows:

1. Construct the pool of all candidate sites and determine the population size N.
2. Conduct a pilot study with the number of sites n' and calculate observed crash frequency, predicted crash frequency, and the calibration factor C based on the pilot study.
3. Determine the required level of confidence and the margin of error.

4. Calculate the required sample size based on the pilot study information using Equation 9-2, Equation 9-3, and Equation 9-6.

If agencies are expected to use this new sample size estimation procedure, the authors recommended a new calibration flow chart for the future calibration project. Figure 9.1 depicts the comparison between this new flow chart and the traditional HSM calibration flow chart with the HSM sample size requirement. As shown in Figure 9.1, compared with the traditional flow chart, the new chart provides a more straightforward and easier calibration process. The site selection effort may be reduced with the new sample size estimation method.

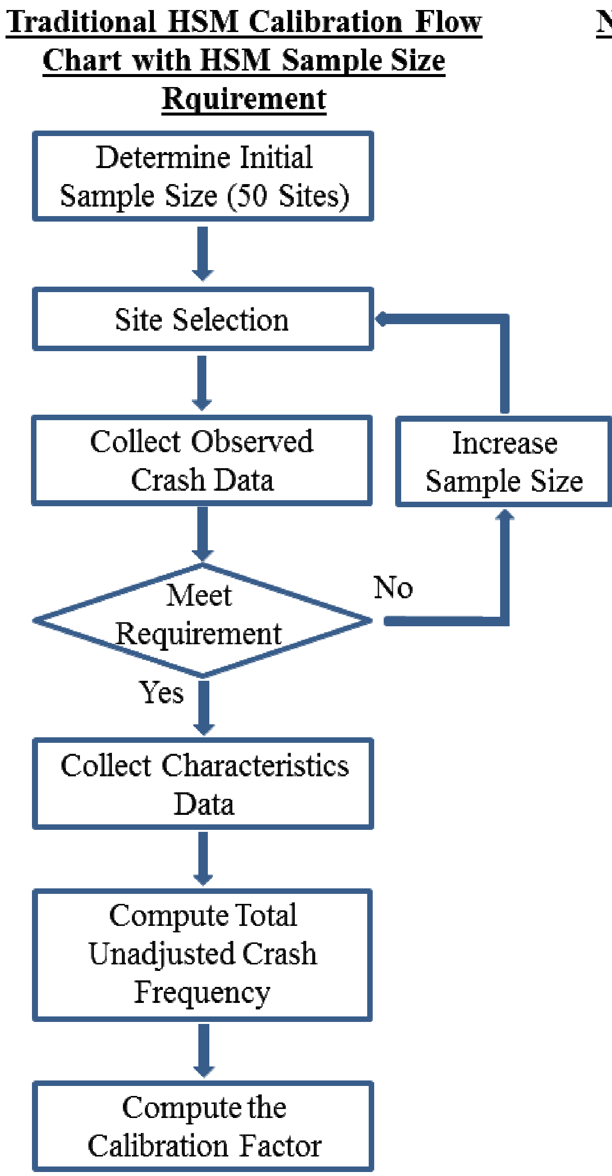


Figure 9.1: Comparisons between Traditional and New Calibration Flow Charts

9.3 Analysis of New Sample Size Determination Method

As shown in Equation 9-6, the required sample size is affected by the level of confidence, the margin of error, the average predicted crash frequency by site, the sample variance of the residuals, and the total population size.

The level of confidence and the margin of error are determined by agencies' calibration expectation or requirement. To increase the precision of the calibration factor, jurisdictions can increase the level of confidence or reduce the margin of error. However, that will also increase the required sample size and may increase the calibration effort for researchers.

The average predicted crash frequency by site is dependent on the road characteristic data for each site. Among all road characteristic data, AADT data have the major effect on the average predicted crash frequency. Higher AADT values will result in higher predicted crash frequency. It is expected that when highways in local conditions experience relatively high traffic volume, the required calibration sample size is expected to be relatively small.

The required sample size is also dependent on the sample variance of the residuals. As the sample variance of the residuals increases, agencies should increase the required sample size.

Finally, the required sample size depends on the total number of available sites in local conditions. For targeted populations, when the number of available sites increases, agencies should increase the required sample size.

9.4 Example Application of New Sample Size Determination Method

R3ST and R4ST are two common types of rural intersections in Oregon. These two types of intersections have very few crashes. Although the author increased the sample size to 200 for each of these two facility types, the target number of crashes of 100 per year still could not be achieved. As shown in Table 9.1, to meet the 100 crashes per year, sample sizes need to reach 560 for R3ST and 295 for R4ST. However, the total numbers of available sites are 466 for 3ST and 225 for 4ST. Therefore, all sites are expected to be sampled until the requirement is met and that is impractical for a calibration project. However the new sample size determination method may help researchers to reduce the required sample size to a practical level. Therefore, the author used this new method to re-estimate the sample sizes for these two facility types.

Before the sample size calculation, the author should make a pilot study. The author considered the existing samples in the Oregon calibration project as the pilot study. The pilot study for each facility type includes 200 sites. (In actual application, the pilot study does not need to have this large number of sites). The calibration factors from the pilot study equal 0.32 and 0.31 (see Table 8.1). With the calibration factors, the author used Equation 9-2 to calculate the residual for each selected site and used Equation 9-3 to calculate the sample variance of the residuals for each of these facility types, R3ST and R4ST. The sample variances of the residuals are 1.2194 for R3ST and 3.6523 for R4ST. Also, based on the predicted crash calculation, the average predicted crash frequencies by site are 1.711 for R3ST and 3.258 for R4ST. With known population sizes for both these facility types, the author can use Equation 9-6 to calculate the required sample size with different levels of confidences and margins of error. Results are shown in Table 9.2 and Table 9.3.

The actual sample size in the calibration project is 200 for each of R3ST and R4ST. Table 9.2 and Table 9.3 indicate that the required sample size varies by different requirement of the level of confidence and the margin of error. For 95% level of confidence, 200 sites result in the margin of error which ranges from 0.05 to 0.1 for 3RST and ranges from 0.01 to 0.05 for 4ST. These ranges of the margin of error are acceptable for a calibration project, and the number of 200 sites is a reasonable and practical sample size for R3ST and R4ST. Agencies can determine their own expected precision of the calibration factor and choose the related sample size based on results in Table 9.2 and Table 9.3. In Table 9.2 and Table 9.3, the sample size is the number of sites selected for the calibration effort, while the population size is the total number of available sites in Oregon.

Table 9.2: Required Sample Sizes of R3ST

Rural Two-Lane, Two-Way Roads Three-leg Stop Controlled Intersections (R3ST)		**Level of Confidence (α)**		
		90%	**95%**	**99%**
Margin of Error	**0.1**	91	119	230
	0.05	229	270	371
	0.01	447	453	461
Population Size		466		
Average Predicted Crash Frequency by Site		1.711		
Sample Variance of Residuals		1.2194		

Table 9.3: Required Sample Sizes of R4ST

Rural Two-Lane, Two-Way Roads Four-leg Stop Controlled Intersections (R4ST)		**Level of Confidence (α)**		
		90%	**95%**	**99%**
Margin of Error	**0.1**	65	83	141
	0.05	140	158	196
	0.01	220	221	224
Population Size		225		
Average Predicted Crash Frequency by Site		3.258		
Sample Variance of Residuals		3.6523		

9.5 Summary

The new sample size estimation method is a statistically reliable approach. Therefore, the author recommends future researchers should use this new method.

10.0 CONCLUSIONS

With calibration factors developed in the calibration project, the State of Oregon can confidently use the HSM predictive methods to evaluate the safety of rural state highways in Oregon. Also, the author provided a detailed outline which can assist future researchers in their site selection, data collection, and data analysis of the calibration project.

During the calibration project, the author located one common obstacle in the data collection process that the minor road AADT of intersections is often unavailable. This thesis provided an effective and practical method to address this problem by developing an AADT estimation model. Future researchers can follow this method to generate their own models to estimate the AADT values.

Although the HSM recommends agencies to develop locally derived values, this thesis proved that the State of Oregon can directly use the HSM default proportions. In addition, the low calibration ratios and current crash reporting thresholds indicate that many PDO crashes are not reported in Oregon. As a result, it appears that the use of fatal and injury level calibration factors is more appropriate for the State of Oregon.

Finally, the author found that the HSM required sample size of 100 crashes per year may not apply to all facilities. To address this issue, practical sample sizes were used in the calibration project. After the project, to improve the future calibration process, the author identified a new sample size estimation method. With this new method, agencies can select the sample size based on the expected precision. In addition, this new method can reduce the effort in the calibration process.

11.0 RECOMMENDATIONS

Sites were mainly selected from the state highway system for the Oregon calibration project. When road characteristic data for county highways are available, it is better to include county highways in the calibration sample to find if there are variations in calibration results.

The data set is time-consuming to develop for the HSM calibration project and many road characteristic data elements may have little effect on the changes of the calibration factor results. The next step is to determine if variables can use HSM default values or other recommended values without affecting the accuracy of the calibration results.

In addition, the AADT estimation model is still time-consuming to generate and some agencies may have difficulty in finding related resources for the model. Future researchers are expected to analyze other methods to estimate the AADT values and find differences in the estimation results. One supplemental estimation method is to use a ratio of minor road AADT to major road AADT to estimate the minor road AADT with known major road AADT.

Besides the calibration procedure, another HSM recommended method could allow local agencies to use the HSM predictive methods by generating the SPF models for local conditions. The next step is to generate the SPF models for Oregon and find differences in the prediction between using the calibration procedure and generating the local SPF models.

12.0 BIBLIOGRAPHY

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APPENDIX

Appendix A Acronyms

Table A.1: Acronyms

Acronym	Term
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
C	Calibration factor
CDS	Crash Data System
CMF	Crash Modification Factor
ft	feet
HSM	Highway Safety Manual
ITS	Intelligent Transportation System
MP	Milepoint
MR3ST	Rural Multilane Three-Leg Stop Controled Intersection
MR4SG	Rural Multilane Four-Leg Signalized Intersections
MR4ST	Rural Multilane Four-Leg Stop Controled Intersection
MRD	Rural Multilane Divided Segment
MRU	Rural Multilane Undivided Segment
ODOT	Oregon Department of Transportation
ORStateHwysFCandNHS	Functional Classification and National Highway System Status on Oregon State Highways
OSU	Oregon State University
OTREC	Oregon Transportation Research and Education Consortium
PDO	Property Damage Only
PSU	Portland State University
R2	Rural Two-Lane, Two-Way Undivided Segment
R3ST	Rural Two-Lane, Two Way Three-Leg Stop Controled Intersection
R4SG	Rural Two-Lane, Two Way Four-Leg Signalized Intersections
R4ST	Rural Two-Lane, Two Way Four-Leg Stop Controled Intersection
SPF	Safety Performance Function
TWLTL	Two Way Left Turn Lane
VIF	Variance Inflation Factor

Appendix B Locally Derived Values

B.1 Rural Two-Lane, Two-Way Roadway Segments Locally Derived Values

Table B.1: R2 Locally Derived Severity Proportions (Year 2004 Crash Data)

Crash severity level	**Locally-Derived Values**
Fatal	3.3
Incapacitating Injury	6.2
Nonincapacitating Injury	25.5
Possible Injury	17.2
Total Fatal Plus Injury	52.2
Property Damage Only	47.8
TOTAL	100.0

Table B.2: R2 Locally Derived Collision Distribution (Year 2004 Crash Data)

Collision type	**Locally-Derived Values**		
	Total fatal and injury	**Property damage only**	**TOTAL (all severity levels combined)**
SINGLE-VEHICLE CRASHES			
Collision with animal	3.8	12.0	7.7
Collision with bicycle	0.4	0.0	0.2
Collision with pedestrian	0.8	0.0	0.4
Overturned	10.4	3.2	7.0
Ran off road	42.1	35.6	39.0
Other single-vehicle crash	1.4	0.6	1.0
Total single-vehicle crashes	58.9	51.4	55.3
MULTIPLE-VEHICLE CRASHES			
Angle collision	0.8	1.1	0.9
Head-on collision	6.8	1.4	4.2
Rear-end collision	18.9	23.0	20.9
Sideswipe collision	5.0	7.3	6.1
Other multiple-vehicle collision	9.6	15.9	12.6
Total multiple-vehicle crashes	41.1	48.6	44.7
TOTAL CRASHES	100.0	100.0	100.0

Table B.3: R2 Locally Derived Nighttime Crash Proportions (Year 2004 Crash Data)

Locally Derived Values		
Proportion of total nighttime crashes by severity level		**Proportion of crashes that occur at night**
Fatal and Injury p_{inr}	**PDO p_{pnr}**	**p_{nr}**
0.5	0.5	0.27

Table B.4: R2 Locally Derived Severity Proportions (Year 2005 Crash Data)

Crash severity level	**Locally-Derived Values**
Fatal	3.1
Incapacitating Injury	7.6
Nonincapacitating Injury	24.5
Possible Injury	19.5
Total Fatal Plus Injury	54.6
Property Damage Only	45.4
TOTAL	100.0

Table B.5: R2 Locally Derived Collision Distribution (Year 2005 Crash Data)

Collision type	**Locally-Derived Values**		
	Total fatal and injury	**Property damage only**	**TOTAL (all severity levels combined)**
SINGLE-VEHICLE CRASHES			
Collision with animal	3.2	10.4	6.4
Collision with bicycle	0.6	0.0	0.3
Collision with pedestrian	0.6	0.0	0.3
Overturned	7.4	3.3	5.6
Ran off road	48.0	41.9	45.3
Other single-vehicle crash	1.5	2.1	1.7
Total single-vehicle crashes	61.3	57.6	59.7
MULTIPLE-VEHICLE CRASHES			
Angle collision	0.9	0.5	0.8
Head-on collision	5.7	1.0	3.7
Rear-end collision	19.5	20.7	20.1
Sideswipe collision	4.2	8.3	6.0
Other multiple-vehicle collision	8.4	11.8	9.9
Total multiple-vehicle crashes	38.7	42.4	40.3
TOTAL CRASHES	100.0	100.0	100.0

Table B.6: R2 Locally Derived Nighttime Crash Proportions (Year 2005 Crash Data)

Locally Derived Values		
Proportion of total nighttime crashes by severity level		**Proportion of crashes that occur at night**
Fatal and Injury p_{inr}	**PDO p_{pnr}**	**p_{nr}**
0.57	0.43	0.29

Table B.7: R2 Locally Derived Severity Proportions (Year 2006 Crash Data)

Crash severity level	**Locally-Derived Values**
Fatal	3.0
Incapacitating Injury	9.3
Nonincapacitating Injury	25.6
Possible Injury	17.1
Total Fatal Plus Injury	54.9
Property Damage Only	45.1
TOTAL	100.0

Table B.8: R2 Locally Derived Collision Distribution (Year 2006 Crash Data)

Collision type	**Locally-Derived Values**		
	Total fatal and injury	**Property damage only**	**TOTAL (all severity levels combined)**
SINGLE-VEHICLE CRASHES			
Collision with animal	2.5	13.7	7.6
Collision with bicycle	0.7	0.0	0.4
Collision with pedestrian	1.0	0.0	0.5
Overturned	8.4	5.1	6.9
Ran off road	50.5	39.5	45.6
Other single-vehicle crash	2.3	1.0	1.7
Total single-vehicle crashes	65.4	59.4	62.7
MULTIPLE-VEHICLE CRASHES			
Angle collision	0.7	0.4	0.6
Head-on collision	5.0	0.7	3.1
Rear-end collision	17.8	20.6	19.1
Sideswipe collision	4.2	5.7	4.9
Other multiple-vehicle collision	6.8	13.2	9.7
Total multiple-vehicle crashes	34.6	40.6	37.3
TOTAL CRASHES	100.0	100.0	100.0

Table B.9: R2 Locally Derived Nighttime Crash Proportions (Year 2006 Crash Data)

Locally Derived Values		
Proportion of total nighttime crashes by severity level		**Proportion of crashes that occur at night**
Fatal and Injury p_{inr}	**PDO p_{pnr}**	**p_{nr}**
0.54	0.46	0.29

Table B.10: R2 Locally Derived Severity Proportions (Three Years' Crash Data)

Crash severity level	**Locally-Derived Values**
Fatal	3.1
Incapacitating Injury	7.7
Nonincapacitating Injury	25.1
Possible Injury	18.0
Total Fatal Plus Injury	54.0
Property Damage Only	46.0
TOTAL	100.0

Table B.11: R2 Locally Derived Collision Distribution (Three Years' Crash Data)

Collision type	**Locally-Derived Values**		
	Total fatal and injury	**Property damage only**	**TOTAL (all severity levels combined)**
SINGLE-VEHICLE CRASHES			
Collision with animal	3.1	12.0	7.2
Collision with bicycle	0.6	0.0	0.3
Collision with pedestrian	0.8	0.0	0.4
Overturned	8.6	3.8	6.4
Ran off road	47.1	39.1	43.5
Other single-vehicle crash	1.7	1.3	1.5
Total single-vehicle crashes	62.0	56.2	59.3
MULTIPLE-VEHICLE CRASHES			
Angle collision	0.8	0.7	0.8
Head-on collision	5.8	1.0	3.6
Rear-end collision	18.8	21.4	20.0
Sideswipe collision	4.4	7.1	5.6
Other multiple-vehicle collision	8.2	13.5	10.6
Total multiple-vehicle crashes	38.0	43.8	40.7
TOTAL CRASHES	100.0	100.0	100.0

Table B.12: R2 Locally Derived Nighttime Crash Proportions (Three Years' Crash Data)

Locally Derived Values		
Proportion of total nighttime crashes by severity level		**Proportion of crashes that occur at night**
Fatal and Injury p_{inr}	**PDO p_{pnr}**	**p_{nr}**
0.54	0.46	0.28

B.2 Rural Two-Lane, Two-Way Intersections Locally Derived Values

Table B.13: R3ST, R4ST and R4SG Locally Derived Severity Proportions (Year 2004 Crash Data)

Collision type	**Locally-Derived Values**		
	R3ST	**R4ST**	**R4SG**
Fatal	2.1	2.0	0.0
Incapacitating injury	4.6	6.7	2.6
Nonincapacitating injury	21.0	19.0	20.5
Possible injury	23.5	21.0	12.8
Total fatal plus injury	51.2	48.7	35.9
Property damage only	48.8	51.3	64.1
TOTAL	100.0	100.0	100.0

Table B.14: R3ST, R4ST, and R4SG Locally Derived Collision Distribution (Year 2004 Crash Data)

Percentage of total crashes by collision type (Locally Derived Values)									
Collision type	**Three-leg stop-controlled intersections**			**Four-leg stop-controlled intersections**			**Four-leg signalized intersections**		
	Fatal and Injury	**Property damage only**	**Total**	**Fatal and injury**	**Property damage only**	**Total**	**Fatal and injury**	**Property damage only**	**Total**
SINGLE-VEHICLE CRASHES									
Collision with animal	0.0	0.0	0.0	0.0	0.8	0.4	0.0	0.0	0.0
Collision with bicycle	0.8	0.0	0.4	2.4	0.0	1.2	0.0	0.0	0.0
Collision with pedestrian	0.0	0.0	0.0	1.6	0.0	0.8	0.0	0.0	0.0
Overturned	3.3	0.9	2.1	0.8	0.0	0.4	0.0	0.0	0.0
Ran off road	12.3	12.9	12.6	3.3	3.9	3.6	0.0	0.0	0.0
Other single-vehicle crash	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.0	0.0
Total single-vehicle crashes	16.4	13.8	15.1	8.9	4.7	6.7	0.0	0.0	0.0
MULTIPLE-VEHICLE CRASHES									
Angle collision	4.1	10.3	7.1	42.3	34.9	38.5	21.4	24.0	23.1
Head-on collision	2.5	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Rear-end collision	36.9	35.3	36.1	22.0	14.7	18.3	50.0	44.0	46.2
Sideswipe collision	1.6	0.9	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Other multiple-vehicle collision	38.5	39.7	39.1	26.8	45.7	36.5	28.6	32.0	30.8
Total multiple-vehicle crashes	83.6	86.2	84.9	91.1	95.3	93.3	100.0	100.0	100.0
TOTAL CRASHES	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table B.15: R3ST, R4ST, and R4SG Locally Derived Nighttime Crash Proportions (Year 2004 Crash Data)

Proportion of crashes that occur at night, p_{ni}	
Intersection Type	**Locally-Derived Values**
R3ST	0.189
R4ST	0.143
R4SG	0.103

Table B.16: R3ST, R4ST and R4SG Locally Derived Severity Proportions (Year 2005 Crash Data)

Collision type	Locally-Derived Values		
	R3ST	**R4ST**	**R4SG**
Fatal	0.9	0.9	2.6
Incapacitating injury	4.1	7.1	0.0
Nonincapacitating injury	20.5	20.4	7.7
Possible injury	26.5	24.8	28.2
Total fatal plus injury	52.1	53.1	38.5
Property damage only	47.9	46.9	61.5
TOTAL	100.0	100.0	100.0

Table B.17: R3ST, R4ST, and R4SG Locally Derived Collision Distribution (Year 2005 Crash Data)

Percentage of total crashes by collision type (Locally Derived Values)									
Collision type	**Three-leg stop-controlled intersections**			**Four-leg stop-controlled intersections**			**Four-leg signalized intersections**		
	Fatal and Injury	**Property damage only**	**Total**	**Fatal and injury**	**Property damage only**	**Total**	**Fatal and injury**	**Property damage only**	**Total**
SINGLE-VEHICLE CRASHES									
Collision with animal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Collision with bicycle	0.0	0.0	0.0	0.8	0.0	0.4	5.9	0.0	2.6
Collision with pedestrian	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.0	0.0
Overturned	1.7	0.0	0.9	1.6	1.0	1.3	0.0	0.0	0.0
Ran off road	11.7	16.2	13.7	0.8	3.1	1.8	0.0	0.0	0.0
Other single-vehicle crash	0.0	1.0	0.5	1.6	0.0	0.9	5.9	0.0	2.6
Total single-vehicle crashes	13.3	17.2	15.1	5.5	4.1	4.9	11.8	0.0	5.1
MULTIPLE-VEHICLE CRASHES									
Angle collision	5.0	3.0	4.1	47.7	28.6	39.4	23.5	31.8	28.2
Head-on collision	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.0	0.0
Rear-end collision	32.5	31.3	32.0	19.5	17.3	18.6	35.3	40.9	38.5
Sideswipe collision	1.7	4.0	2.7	0.8	0.0	0.4	0.0	0.0	0.0
Other multiple-vehicle collision	47.5	44.4	46.1	25.8	50.0	36.3	29.4	27.3	28.2
Total multiple-vehicle crashes	86.7	82.8	84.9	94.5	95.9	95.1	88.2	100.0	94.9
TOTAL CRASHES	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table B.18: R3ST, R4ST, and R4SG Locally Derived Nighttime Crash Proportions (Year 2005 Crash Data)

Proportion of crashes that occur at night, p_{ni}	
Intersection Type	**Locally-Derived Values**
3ST	0.142
4ST	0.137
4SG	0.154

Table B.19: R3ST, R4ST and R4SG Locally Derived Severity Proportions (Year 2006 Crash Data)

Collision type	Locally-Derived Values		
	R3ST	R4ST	R4SG
Fatal	0.9	1.5	0.0
Incapacitating injury	6.4	6.3	4.4
Nonincapacitating injury	22.8	25.4	13.3
Possible injury	26.9	20.2	33.3
Total fatal plus injury	57.1	53.3	51.1
Property damage only	42.9	46.7	48.9
TOTAL	100.0	100.0	100.0

Table B.20: R3ST, R4ST, and R4SG Locally Derived Collision Distribution (Year 2006 Crash Data)

Percentage of total crashes by collision type (Locally Derived Values)									
Collision type	Three-leg stop-controlled intersections			Four-leg stop-controlled intersections			Four-leg signalized intersections		
	Fatal and Injury	Property damage only	Total	Fatal and injury	Property damage only	Total	Fatal and injury	Property damage only	Total
SINGLE-VEHICLE CRASHES									
Collision with animal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Collision with bicycle	1.6	0.0	0.9	2.8	0.0	1.5	0.0	0.0	0.0
Collision with pedestrian	0.8	0.0	0.5	2.8	0.0	1.5	4.3	0.0	2.2
Overturned	2.4	2.1	2.3	1.4	0.8	1.1	0.0	0.0	0.0
Ran off road	10.4	12.8	11.4	4.8	10.2	7.4	0.0	0.0	0.0
Other single-vehicle crash	1.6	1.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0
Total single-vehicle crashes	16.8	16.0	16.4	11.7	11.0	11.4	4.3	0.0	2.2
MULTIPLE-VEHICLE CRASHES									
Angle collision	4.8	3.2	4.1	37.2	22.8	30.5	30.4	18.2	24.4
Head-on collision	0.8	0.0	0.5	1.4	0.8	1.1	0.0	0.0	0.0
Rear-end collision	30.4	33.0	31.5	12.4	28.3	19.9	43.5	31.8	37.8
Sideswipe collision	1.6	1.1	1.4	0.7	0.0	0.4	0.0	4.5	2.2
Other multiple-vehicle collision	45.6	46.8	46.1	36.6	37.0	36.8	21.7	45.5	33.3
Total multiple-vehicle crashes	83.2	84.0	83.6	88.3	89.0	88.6	95.7	100.0	97.8
TOTAL CRASHES	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table B.21: R3ST, R4ST, and R4SG Locally Derived Nighttime Crash Proportions (Year 2006 Crash Data)

Proportion of crashes that occur at night, p_{ni}	
Intersection Type	**Locally-Derived Values**
3ST	0.215
4ST	0.228
4SG	0.133

Table B.22: R3ST, R4ST and R4SG Locally Derived Severity Proportions (Three Years' Crash Data)

Collision type	Locally-Derived Values R3ST	Locally-Derived Values R4ST	Locally-Derived Values R4SG
Fatal	1.3	1.5	0.8
Incapacitating injury	5.0	6.7	2.4
Nonincapacitating injury	21.4	21.7	13.8
Possible injury	25.6	21.9	25.2
Total fatal plus injury	53.4	51.7	42.3
Property damage only	46.6	48.3	57.7
TOTAL	100.0	100.0	100.0

Table B.23: R3ST, R4ST, and R4SG Locally Derived Collision Distribution (Three Years' Crash Data)

Percentage of total crashes by collision type (Locally Derived Values)									
Collision type	Three-leg stop-controlled intersections			Four-leg stop-controlled intersections			Four-leg signalized intersections		
	Fatal and Injury	Property damage only	Total	Fatal and injury	Property damage only	Total	Fatal and injury	Property damage only	Total
SINGLE-VEHICLE CRASHES									
Collision with animal	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0
Collision with bicycle	0.8	0.0	0.4	2.0	0.0	1.1	1.9	0.0	0.8
Collision with pedestrian	0.3	0.0	0.1	1.8	0.0	0.9	1.9	0.0	0.8
Overturned	2.5	1.0	1.8	1.3	0.6	0.9	0.0	0.0	0.0
Ran off road	11.4	13.9	12.6	3.0	5.9	4.4	0.0	0.0	0.0
Other single-vehicle crash	0.5	0.6	0.6	0.8	0.0	0.4	1.9	0.0	0.8
Total single-vehicle crashes	15.5	15.5	15.5	8.8	6.8	7.9	5.6	0.0	2.4
MULTIPLE-VEHICLE CRASHES									
Angle collision	4.6	5.8	5.2	42.2	28.8	35.9	25.9	24.6	25.2
Head-on collision	1.1	0.0	0.6	0.8	0.3	0.5	0.0	0.0	0.0
Rear-end collision	33.2	33.3	33.3	17.7	20.3	18.9	42.6	39.1	40.7
Sideswipe collision	1.6	1.9	1.8	0.5	0.0	0.3	0.0	1.4	0.8
Other multiple-vehicle collision	43.9	43.4	43.6	30.1	43.8	36.5	25.9	34.8	30.9
Total multiple-vehicle crashes	84.5	84.5	84.5	91.2	93.2	92.1	94.4	100.0	97.6
TOTAL CRASHES	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table B.24: R3ST, R4ST, and R4SG Locally Derived Nighttime Crash Proportions (Three Years' Crash Data)

Proportion of crashes that occur at night, p_{ni}	
Intersection Type	**Locally-Derived Values**
3ST	0.182
4ST	0.172
4SG	0.130

B.3 Rural Multilane Segment Locally Derived Values

Table B.25: MRU Locally Derived Collision Distribution (Year 2004 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.036	0.056	0.074	0.019
Sideswipe	0.183	0.132	0.173	0.228
Rear-end	0.359	0.368	0.185	0.352
Angle	0.010	0.007	0.012	0.012
Single	0.294	0.319	0.370	0.272
Other	0.118	0.118	0.185	0.117
SV run-off-rd, Head-on, Sideswipe	0.399			

Table B.26: MRU Locally Derived Nighttime Crash Proportions (Year 2004 Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.571	0.429	0.206

Table B.27: MRD Locally Derived Collision Distribution (Year 2004 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.055	0.067	0.067	0.047
Sideswipe	0.123	0.100	0.133	0.140
Rear-end	0.356	0.333	0.133	0.372
Angle	0.000	0.000	0.000	0.000
Single	0.411	0.467	0.600	0.372
Other	0.055	0.033	0.067	0.070
SV run-off-rd, Head-on, Sideswipe	0.493			

Table B.28: MRD Locally Derived Nighttime Crash Proportions (Year 2004 Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.550	0.450	0.274

Table B.29: MRU Locally Derived Collision Distribution (Year 2005 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.049	0.092	0.155	0.012
Sideswipe	0.146	0.096	0.100	0.188
Rear-end	0.329	0.367	0.200	0.297
Angle	0.019	0.028	0.036	0.012
Single	0.344	0.339	0.436	0.348
Other	0.114	0.078	0.073	0.145
SV run-off-rd, Head-on, Sideswipe	0.435			

Table B.30: MRU Locally Derived Nighttime Crash Proportions (Year 2005 Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.518	0.482	0.241

Table B.31: MRD Locally Derived Collision Distribution (Year 2005 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.000	0.000	0.000	0.000
Sideswipe	0.206	0.080	0.091	0.289
Rear-end	0.397	0.440	0.455	0.368
Angle	0.000	0.000	0.000	0.000
Single	0.365	0.480	0.455	0.289
Other	0.032	0.000	0.000	0.053
SV run-off-rd, Head-on, Sideswipe	0.492			

Table B.32: MRD Locally Derived Nighttime Crash Proportions (Year 2005 Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.389	0.611	0.286

Table B.33: MRU Locally Derived Collision Distribution (Year 2006 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.040	0.083	0.118	0.012
Sideswipe	0.148	0.101	0.097	0.178
Rear-end	0.305	0.339	0.194	0.283
Angle	0.014	0.024	0.032	0.008
Single	0.390	0.375	0.473	0.399
Other	0.103	0.077	0.086	0.120
SV run-off-rd, Head-on, Sideswipe	0.458			

Table B.34: MRU Locally Derived Nighttime Crash Proportions (Year 2006 Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		Proportion of crashes that occur at night
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.357	0.643	0.263

Table B.35: MRD Locally Derived Collision Distribution (Year 2006 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.021	0.059	0.067	0.000
Sideswipe	0.128	0.000	0.000	0.200
Rear-end	0.170	0.235	0.200	0.133
Angle	0.021	0.059	0.067	0.000
Single	0.574	0.588	0.600	0.567
Other	0.085	0.059	0.067	0.100
SV run-off-rd, Head-on, Sideswipe	0.574			

Table B.36: MRD Locally Derived Nighttime Crash Proportions (Year 2006 Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		Proportion of crashes that occur at night
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.412	0.588	0.362

Table B.37: MRU Locally Derived Collision Distribution (Three Years' Crash Data)

Collision type	**Locally-Derived Values**			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.040	0.083	0.118	0.012
Sideswipe	0.148	0.101	0.097	0.178
Rear-end	0.305	0.339	0.194	0.283
Angle	0.014	0.024	0.032	0.008
Single	0.390	0.375	0.473	0.399
Other	0.103	0.077	0.086	0.120
SV run-off-rd, Head-on, Sideswipe	0.458			

Table B.38: MRU Locally Derived Nighttime Crash Proportions (Three Years' Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.357	0.643	0.263

Table B.39: MRD Locally Derived Collision Distribution (Three Years' Crash Data)

Collision type	**Locally-Derived Values**			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.027	0.042	0.049	0.018
Sideswipe	0.153	0.069	0.073	0.207
Rear-end	0.322	0.347	0.244	0.306
Angle	0.005	0.014	0.024	0.000
Single	0.437	0.500	0.561	0.396
Other	0.055	0.028	0.049	0.072
SV run-off-rd, Head-on, Sideswipe	0.514			

Table B.40: MRD Locally Derived Nighttime Crash Proportions (Three Years' Crash Data)

Locally-Derived Values		
Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
0.455	0.545	0.301

B.4 Rural Mutilane Intersections Locally Derived Values

Table B.41: MR3ST Locally Derived Collision Distribution (Year 2004 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Three-leg intersections with minor road stop control				
Head-on	0.009	0.008	0.014	0.011
Sideswipe	0.005	0.000	0.000	0.011
Rear-end	0.269	0.320	0.155	0.202
Angle	0.041	0.064	0.099	0.011
Single	0.137	0.152	0.183	0.117
Other	0.539	0.456	0.549	0.649
SV run-off-rd, Head-on, Sideswipe	0.114			

Table B.42: MR4ST Locally Derived Collision Distribution (Year 2004 Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Four-leg intersections with minor road stop control				
Head-on	0.005	0.009	0.014	0.000
Sideswipe	0.005	0.000	0.000	0.011
Rear-end	0.156	0.159	0.086	0.152
Angle	0.405	0.469	0.529	0.326
Single	0.054	0.018	0.014	0.098
Other	0.376	0.345	0.357	0.413
SV run-off-rd, Head-on, Sideswipe	0.059			

Table B.43: MR3ST and MR4ST Locally Derived Nighttime Crash Proportions (Year 2004 Crash Data)

Roadway Type	Locally-Derived Values		
	Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
	Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
3ST	0.515	0.485	0.151
4ST	0.553	0.447	0.174

Table B.44: MR3ST Locally Derived Collision Distribution (Year 2005 Crash Data)

Collision type	**Locally-Derived Values**			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Three-leg intersections with minor road stop control				
Head-on	0.012	0.020	0.031	0.000
Sideswipe	0.006	0.010	0.000	0.000
Rear-end	0.193	0.192	0.109	0.189
Angle	0.064	0.121	0.125	0.014
Single	0.105	0.101	0.109	0.108
Other	0.620	0.556	0.625	0.689
SV run-off-rd, Head-on, Sideswipe	0.094			

Table B.45: MR4ST Locally Derived Collision Distribution (Year 2005 Crash Data)

Collision type	**Locally-Derived Values**			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Four-leg intersections with minor road stop control				
Head-on	0.010	0.016	0.025	0.000
Sideswipe	0.010	0.000	0.000	0.024
Rear-end	0.124	0.128	0.074	0.119
Angle	0.411	0.440	0.457	0.369
Single	0.043	0.056	0.049	0.024
Other	0.402	0.360	0.395	0.464
SV run-off-rd, Head-on, Sideswipe	0.038			

Table B.46: MR3ST and MR4ST Locally Derived Nighttime Crash Proportions (Year 2005 Crash Data)

Roadway Type	**Locally-Derived Values**		
	Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
	Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
3ST	0.615	0.385	0.152
4ST	0.538	0.462	0.152

Table B.47: MR3ST Locally Derived Collision Distribution (Year 2006 Crash Data)

Collision type	**Locally-Derived Values**			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Three-leg intersections with minor road stop control				
Head-on	0.000	0.000	0.000	0.000
Sideswipe	0.021	0.017	0.027	0.028
Rear-end	0.265	0.265	0.227	0.264
Angle	0.032	0.034	0.013	0.028
Single	0.111	0.094	0.093	0.139
Other	0.571	0.590	0.640	0.542
SV run-off-rd, Head-on, Sideswipe	0.090			

Table B.48: MR4ST Locally Derived Collision Distribution (Year 2006 Crash Data)

Collision type	**Locally-Derived Values**			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Four-leg intersections with minor road stop control				
Head-on	0.000	0.000	0.000	0.000
Sideswipe	0.013	0.016	0.014	0.010
Rear-end	0.166	0.168	0.100	0.163
Angle	0.327	0.376	0.414	0.265
Single	0.067	0.080	0.100	0.051
Other	0.426	0.360	0.371	0.510
SV run-off-rd, Head-on, Sideswipe	0.058			

Table B.49: MR3ST and MR4ST Locally Derived Nighttime Crash Proportions (Year 2006 Crash Data)

Roadway Type	**Locally-Derived Values**		
	Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
	Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
3ST	0.600	0.400	0.132
4ST	0.710	0.290	0.164

Table B.50: MR3ST Locally Derived Collision Distribution (Three Years' Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Three-leg intersections with minor road stop control				
Head-on	0.007	0.009	0.014	0.004
Sideswipe	0.010	0.009	0.010	0.013
Rear-end	0.245	0.264	0.167	0.217
Angle	0.045	0.070	0.076	0.017
Single	0.119	0.117	0.129	0.121
Other	0.573	0.531	0.605	0.629
SV run-off-rd, Head-on, Sideswipe	0.100			

Table B.51: MR4ST Locally Derived Collision Distribution (Three Years' Crash Data)

Collision type	Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO
Four-leg intersections with minor road stop control				
Head-on	0.005	0.008	0.014	0.000
Sideswipe	0.009	0.006	0.005	0.015
Rear-end	0.149	0.152	0.086	0.146
Angle	0.380	0.427	0.466	0.318
Single	0.055	0.052	0.054	0.058
Other	0.402	0.355	0.376	0.464
SV run-off-rd, Head-on, Sideswipe	0.052			

Table B.52: MR3ST and MR4ST Locally Derived Nighttime Crash Proportions (Three Years' Crash Data)

Roadway Type	Locally-Derived Values		
	Proportion of total night-time crashes by severity level		**Proportion of crashes that occur at night**
	Fatal and injury, p_{inr}	PDO, p_{pnr}	p_{nr}
3ST	0.571	0.429	0.145
4ST	0.600	0.400	0.164